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2. A 50-word summary should accompany the paper.

3. The manuscript (a ribbon copy and two copies) should be double-spaced on one side of 8½-in. by 11-in. paper. Papers that were originally prepared for oral presentation must be rewritten into the third person before being submitted.

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8. Papers should average about 12,000 words in length and should be no longer than 18,000 words. As an approximation, each full page of typed text, table, or illustration is the equivalent of 300 words.

Further information concerning the preparation of technical papers is contained in the "Technical Publications Handbook" which can be obtained from the Society.

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HIGHWAY AND BRIDGE SURVEYS: PRELIMINARY SURVEY[a]

Progress Report of the Committee on Highway and Bridge
Surveys of the Surveying and Mapping Division
(Proc. Paper 1697)

INTRODUCTION

Purpose and Scope of Preliminary Survey

The preliminary survey is a large-scale study of one or more feasible routes. Its result is a paper location, which defines the line for the subsequent location survey.

Essentially a field-to-office process, the preliminary survey consists of the assembly and analysis of physical data. Within the established route area, topographic, geologic and cultural features are measured and noted. The various field data are then translated into maps, profiles and frequently cross-sections, which enable the engineer to complete his preliminary analysis.

Taking into account the previously established design criteria (and land-use factors) the engineer determines preliminary grades and alignment and prepares an approximate cost estimate.

The resulting paper alignment should show enough ties to existing topography to permit a location party to stake it out. The preliminary field survey, then, should provide sufficient information for full establishment of the paper location. This much is a minimum. In many cases field detail for final design also may be obtained economically during the preliminary survey phase.

Choice of Mapping Methods

Two approaches are available for preliminary-survey mapping: aerial surveys and ground surveys either separately or in various combinations. Because aerial surveys cost about the same for relatively broad bands as for narrow bands they are likely to be more adequate and economical than ground surveys in the following cases:

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a. This paper will form the basis for a chapter in a proposed ASCE Manual of Engineering Practice.

1) Where reconnaissance was unable to approximate closely the final alignment (e.g.: all-new location in rugged terrain; where land use and values vary widely).

2) Where a wide right-of-way, such as that for an Interstate Highway, is programmed.

All-aerial surveys have the inherent feature, usually desirable, of concealing the details of probable location from those who would misuse such information for financial advantage. Ground-control work for aerial surveys reveals but little of the highway engineer's intentions.

All-ground Survey

The least demanding preliminary survey is one involving a situation where the alignment is well-defined, narrow rights-of-way are contemplated and problems of culture are few. Ground surveys, beginning with a traverse baseline, probably will furnish the necessary data economically. Additional operations include profile levels, cross-sections and ties to land lines and cultural objects.

Aerial Photographs

If the problem is more complex, aerial photographic aids should be considered. The simplest aid is the photograph itself. Because the final line is more closely defined than it was during reconnaissance, a narrower strip can be studied, and hence a larger photoscale is utilized. Enlargements up to five times are feasible.

Among the benefits to be derived from contact photos and enlargements are:

1) Intensive photo-interpretation.

2) Clarification of field notes.

3) Scaling of approximate measurements for checking distances and for obtaining non-critical dimensions.

4) Field-survey planning, in order to avoid unnecessary measurements and to guide inexperienced parties.

As a field-survey planning aid alone, the photographs may pay for themselves, for if they eliminate one party-day of unnecessary work per mile of line much of the photo cost is recovered. Instructions may be written directly on the matte surface of a photo, or on a sketch quickly traced from the photo. The sketch is especially useful in interchange or other complicated areas.

Frequently at little extra expense an uncontrolled mosaic made from the photos is more helpful in field survey planning. In fact, in some cases the uncontrolled mosaic is a satisfactory map on which to establish the centerline. A combination of flat terrain, low-type road and sparse settlement could make such an inexpensive approach acceptable. Detailed mapping still would be required at structure sites, and elevations of controlling points should be obtained for suitable study of grades.

Stereo-Planimetric Maps

A controlled mosaic, on which horizontal measurements may be made with fair precision, approaches a stereo-compiled planimetric map in cost. The

latter is more precise and more useful in highway work, so should be considered more desirable than single photos as the complexity of the project increases.

A preponderance of horizontal measurements, such as would be required in a settled area with fairly level terrain, virtually dictates a stereo-compiled planimetric map as the most economical basis of alignment studies. In appraising the economy of such a map the engineer should count not only the saving of field-party days but also the drafting time that otherwise would be spent in plotting most of the field notes of a conventional ground survey.

There remains, of course, the necessary ground-control traverse, which fixes recognizable horizontal position points in the photographs. If horizontal bridging is done by stereo-instruments, or stereo templets, about one such point is needed in every fifth photograph. If no bridging is done, two points will be needed in each photograph. The ground-control traverse, corresponding to the baseline traverse cited above for all-ground surveys, also can be the profile-level line. Side shots or auxiliary level lines will complete vertical ground control for orienting photos in stereoplotting instruments. The traverse and profile level line also will control any required cross-sectioning.

Stereo-Topographic Maps

In rugged terrain, particularly where a broad strip of topography is required, even the most approximate cross-sectioning by ground methods becomes expensive. Here the economy of a stereo-compiled topographic map complete with contours should be considered.

For preliminary-survey purposes few horizontal measurements need to be closer than they can be scaled off a general-purpose, large-scale map of standard accuracy.

To the highway engineer schooled in the use of U.S.G.S. quadrangle sheets, the topographic map is a familiar tool. At the scales and contour intervals needed for the preliminary survey analysis, he can plot both baseline profiles and ground cross-profiles with ease and sufficient accuracy as he performs his grade and alignment studies. Moreover, he can utilize all the data and other benefits previously cited for planimetric maps and for the photographs from which his new map was made. In most cases his only field-survey expense is for photogrammetric ground control. Furthermore, he already has obtained part of the survey data he will need for highway design.

Map Scales

The proportion of final design data available from the preliminary mapping depends on the scale and contour interval chosen, which in turn depend on factors like the breadth of coverage desired for preliminary-survey purposes, density of culture and steepness of terrain slopes. Usual map scale limits are 1 in. = 400 ft and 1 in. = 100 ft. Contour intervals would be 10 ft or 5 ft; occasionally 2 ft.

Critical areas like structure sites may be mapped at a larger scale. Photogrammetric site maps may be economical if flying is done at the same time as for the strip map. Otherwise a ground surveying structure-site topographic map is likely to be cheaper.

Procurement of New Maps

A few state highway departments have their own photogrammetry departments, manned by experts who can advise on the correct mapping applications for each survey situation. Most organizations rely upon the commercial air-mapping companies, several of which are competent in the practice of highway engineering also. In any case substantial aid in the procurement of highway maps is available in "Reference Guide Outline - Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways," published in 1956 by the U.S. Bureau of Public Roads.

Mapping Procedures

The choice of preliminary-survey methods should be an informed one, based on an advance cost analysis that takes into account the overall project schedule and the time requirements of the various techniques. In the following two sections the steps of all-ground surveys and of photogrammetric surveys are outlined. Insofar as they furnish a check-list of the respective operations, they will assist in the comparative analysis of methods.

Ground Surveys

If the preliminary survey is made by the conventional means of a baseline traverse on the ground, this line usually is the first stake-out in the field. Such a stake-out is generally expected to be fairly close to the finally selected line.

The baseline traverse may be simply a series of connecting straight lines, if the curvature necessary to connect the tangents is such that the curves will not deviate greatly from the tangents. Where sweeping curves with large external distances are necessary, it may be better to run them in as part of the original baseline so as to avoid the necessity for taking topography too far from the base in covering the area in which the curve is located.

The baseline traverse should be stationed continuously from the beginning to the end of the survey. The survey should be executed so as to obtain third-order accuracy, and ties should be made to any available points of known state plane coordinate position. In flat or moderately rolling terrain stakes at every 100-ft station may be sufficient, but on rougher ground stakes at intermediate points may be desirable. All angle points should be marked by hubs driven flush with ground, with a marked guard-stake showing the station number.

Angles between connecting lines should be measured in accordance with accepted route-surveying procedures, and angle points should be carefully referenced to two or more points established well outside the area that later may be occupied by roadway construction. On long tangents, points on tangent should be established and referenced at least every 500 ft, consistent with requirements of intervisibility.

To furnish data for a profile of the baseline, levels should be run over all marked stations, as well as all important breaks in the ground. Elevations should be taken at all cross roads, streams and other critical points on the line. The levels should be based upon the 1929 mean sea level datum, and check levels should be run over the entire line. Ground shots should be read to the nearest 0.1 ft and sights on turning points and intermediate bench marks to the nearest 0.01 ft. Intermediate bench marks should be established and

referenced at least every 1000 ft. Where practicable they should be placed so as to avoid subsequent disturbance by construction work.

After the baseline has been staked and levels run over it, the topography may be taken by one of several methods. Probably the simplest method is by cross-sections. On fairly flat terrain cross-sections are sometimes taken by the level party at the same time as the profile levels are taken. Another method frequently used for cross-sections involves the use of the Locke level, by a party following the stake-out and profile level parties. Observations are made out at right angles from each station as far as considered necessary to cover the area of construction. In many cases where, for some reason, wider deviations of the location from the baseline may be expected, the topography may be more rapidly taken by transit stadia, by plane-table, or by a combination of the two.

At the time topography is taken, the location of all structures and other features, such as buildings, fences, property lines, limits of cultivation, trees, roads, streams, culverts, bridges, etc., should be noted so they can be shown on the map.

The preliminary map prepared from the data gathered by the conventional ground survey method is usually called a strip map because it is plotted on a continuous roll of detail paper. The map may or may not include the plotting of contours, depending upon the complexity of the project. The minimum information to be shown on the map will be the plot of the baseline, and all planimetric detail. While this may be sufficient data from which to project the preliminary line on regular ground, it may be desirable to have it supplemented with detailed maps showing contours of those areas where complex structures or intersections are to be located.

The planimetric strip map also should show surface and subsurface information that might affect the location. Such information includes fence lines, woodland cover, limits of bogs and other undesirable soil and geologic features, overhead and subsurface utility lines. It is noted that aerial photographs are useful aids to survey parties in locating the foregoing features.

Photogrammetric Surveys

The following discussion of photogrammetric preliminary surveys applies to the preparation of a topographic map. The methods are substantially the same for planimetric maps, except that in the latter case a large proportion of stereoplotting instrument time (and money) is saved. Plotting still must be done stereoscopically so that all horizontal points will bear the correct relationship to each other.

Steps of preliminary aerial topographic mapping are:

1) Photographic mission.
2) Ground-control surveying.
3) Stereoplotting.
4) Drafting.

Precurement of photographs is not only the first step but also the one that largely determines the feasible completion date for mapping. Where there is foliage on the route selected by reconnaissance, the line must be flown when there are no leaves. Snow cover inhibits good photography because it masks features that must be seen for effective stereoplotting. In some parts of the United States aerial photography thus is confined to a short period in the fall

and a longer period in the spring. In other areas most of the winter may be available. In southwestern desert areas there is practically no closed season.

Clear skies also are essential to effective photo-mapping. Ready reference to the chances for clear-skies is found in U.S. Weather Bureau tables giving the average number of clear-skies days each month in various parts of the country. Similar information is found in "Manual of Photogrammetry," published by The American Society of Photogrammetry, Washington D.C. (1952).

When the ground can be seen through clear air, and the photographic aircraft is at location, photography takes about a minute for each two miles of line. The crew flies a fixed altitude along flight lines established on the preliminary map, then rushes film rolls to the laboratory for developing, printing and a quick inspection. Deviations from flight line and defects of overlap can send the crew back for a re-flight. The experienced crew, however, will need to make few re-flights.

Ground control is next. Upon the matte surface of contact aerial photos, recognizable features are marked. Together with available control data, the survey party takes these photos into the field, and locates the marked picture points both horizontally and vertically.

As a minimum requirement, one horizontal point near the center of every fifth photograph and two vertical points, one near each edge of every third or fourth photo must be observed. Additional required control points then may be "bridged-in" to intervening pictures with a first-order stereoplotting instrument. If no vertical bridging is done, two points will be needed for each photograph.

It is likely, however, that for highway-survey purposes enough use subsequently will be made of ground-control points to warrant the expense of ground-surveyed monuments and bench marks for all control required for stereo-compilation. A main traverse, following the center of flight line, corresponds to the base line described above in "Ground Surveys." Of either third order or second order, depending on the spacing of existing federal control monuments, this base line traverse becomes the framework of later location and construction surveys. It should be referenced with these later uses in mind. Bench-levels are run to the specified "wing points" of the photos and duly checked.

Stereoplotting now can proceed. Glass positives of overlapping photo pairs are inserted in stereoplotting instruments projectors and oriented with respect to their recognizable control points. The orientation process in effect duplicates at small scale the relative positions of the airborne camera at its two successive instants of film exposure. Thus a true three-dimensional image, or model, of a portion of the route strip is established within the instrument. Through the instrument's mechanism both vertical and horizontal dimensions can be measured on the image. Planimetric lines and the contours are plotted on a sheet called the manuscript.

Stereoplotting time varies widely with the complexity of terrain and the skill of the operator. A rule-of-thumb average is one man-instrument-day per model. In such an average case the progress on a 1 in. = 200 ft map with 5-ft contours would be about two-thirds of a mile per day in a single stereoplotting instrument. Extended work days and more instruments make greater progress possible.

The manuscript or a photographic print of it occasionally is used directly for alignment-study purposes, but most engineers prefer to add one more step, drafting the finished map on a tracing medium. Where tracing from the

manuscript is performed, more care is taken in the positioning of lettering and symbols, to the end that the engineer has clean, uncluttered prints for his alignment studies.

Location Studies

Selection of Alignment

The selection of alignment, and the extent to which it may be chosen to fit the ground economically, depends upon the geometric design standards adopted for the construction. These standards in turn depend upon the amount and type of transportation usage expected.

Standards may range from the criteria for widths, curvature, grades and sight distances sufficient to accommodate sparce rural traffic at moderate speeds, to those criteria necessary for large volumes of heavy traffic at high speeds. Such criteria have been set up in the publication: "A Policy on Geometric Design of Rural Highways" (1954) issued by the American Association of State Highway Officials.

With the classification of service established, and the appropriate standards of alignment fixed thereby, ordinarily the combination of tangents and horizontal curvature is sought that will best fit the surface of the ground within the limits of the criteria.

At the same time consideration must be given to factors other than the ground fit. In many cases, right-of-way requirements may force a compromise in the alignment, so as to avoid the following: costly or undesirable property severances; the necessity of taking high-priced property where lower prices may be obtainable on another location; the destruction or removal of buildings; the location of the right-of-way through, or too close to cemeteries, churches and schools.

As a general rule it is better, where possible, to take rights-of-way along property lines, so as to avoid severances of parcels.

The question of the degree of limiting access to the highway by abutting property owners is one that may greatly influence the necessary width of right-of-way. Where access is not to be limited, the right-of-way should be sufficiently wide beyond the construction limits to prevent construction of unsightly or undesirable structures so close to the roadway as to create hazards to safety. Where the access is to be controlled or limited, the comparative widths to be taken may be relatively less than for unlimited access.

When studies indicate that a certain minimum facility will accomodate the traffic for several years before the ultimate facility is needed, the minimum facility should be built, but land should be taken for the ultimate.

While consideration of right-of-way problems may be the principal influence modifying the best choice of alignment, there are several other factors to be taken into account as well.

The effect of the proposed road upon existing or future utilities above, on or under the ground may be of sufficient importance to require changes in alignment to avoid relocating such utilities.

The alignment of the road with reference to other roads, railroads or utilities, may bear importantly upon the location, so that the location that will best provide suitable places for crossings, or diminish the necessity for crossings, may be the best selection.

In the case of a high-type limited access highway the matter of an

interchange with another road may dictate an alignment that will intersect the other road at a place, at an angle and in terrain that will best permit the interchange to be constructed.

The requirements for drainage of the highway may have considerable influence upon its alignment. An alignment that will provide better lateral and longitudinal drainage, or require less subsurface drainage, or one that will avoid locations over poorly drained ground areas, is preferable to one less favorably situated in this regard. Long flat grades in through cuts should be avoided.

The same statements that were made above regarding crossings of roads and railroads may be reiterated for stream crossings that will require culverts or bridges. The most suitable alignment is one that avoids, as far as possible, the necessity for such drainage structures, or one that crosses the streams at the more favorable sites or skews for their construction.

All these considerations must be weighed in the selection of the alignment. In addition to them, the fit-to-ground consideration prevails, but the best fit may be unattainable under the modifications made necessary by the influence of the other factor upon the overall economics of the problem.

Study of Grade Lines

Most of the factors previously mentioned under "Selection of Alignment" also influence the study of grade lines. Alignments and grade lines have mutual dependence on each other. The best alignment does not necessarily permit economical grades to be selected within the limits of the established criteria, nor vice versa.

The primary effort of the preliminary designer should be to obtain the balance between alignment and grade that will permit construction of the highway with the least amount of earthwork necessary, and with as close a balance between excavation and embankment quantities as is possible considering the qualifying circumstances.

One of the principal influences upon the choice of grade lines is the necessity for maintaining proper stopping and passing sight distances consistent with the service requirements of the road. This influence coupled with the necessity for establishing proper sight-distance grades and vertical-curve connections for structures, makes the task an exacting one.

Earthwork Consideration

Earthwork required by the chosen line and grade is perhaps the most important of the many factors to be considered in a location. When the needs of all the other factors have been satisfied then the best line and grade is the combination that gives the minimum total cost for earthwork. The ideal situation yields the minimum quantities of excavation with the quantities of embankment so balanced in sections as to require a minimum of haulage without overhaul. This may be an extremely difficult and rare condition to achieve so compromises frequently are necessary.

Other factors affect earthwork costs: for example, the unit cost of excavation may be less in one classification of material than in another; or the length of haul and amount of required overhaul may make wastage and/or borrow desirable as an economical alternative. The solutions of these problems of alternates lie in economic analyses of road user benefits and costs of the alternates.

The estimates of earthwork quantities may be computed by one of several methods, the choice depending upon consideration of the terrain and accuracy required.

The simplest method, one which is generally adapted to fairly flat or gently sloping terrain, is by standard level sections, in which the area of the cross-section in cut, or fill, is merely that of a trapezoid with a constant roadway width and side-slope, and a height equal to the depth of cut or fill on the centerline.

Where the terrain may be considered too irregular to obtain the desired degree of accuracy by the method of level sections, the next step in accuracy will be obtained by the use of cross-sections, either as taken in the field, or stripped from the contour map. The necessary frequency of cross-sections and the consequent lengths of prisms will again depend upon the regularity of the terrain or the degree of accuracy desired in the resulting quantities.

It is noted here that many tests in recent years have shown that ordinary ground-surveyed cross-sections and cross-sections stripped from good maps of sufficiently large scale yield result of comparable accuracy.

Still another method, available where the map scale is not smaller than 1 in. = 200 ft and the contour interval not more than 5 ft, is that of superimposing the contours of the earthwork on the topographic map. The volumes of each mass of cut or fill are determined by obtaining the sum of the areas of each contour layer by a continuous run of a planimeter around each in succession, and multiplying this sum by the contour interval.

Further details concerning methods of earthwork computation are available in standard texts on the subject. The purpose, of course, of earthwork computation as it pertains to preliminary surveys is to select the line and grade which satisfies the geometric design criteria at the least cost for the transportation benefit sought.

Respectfully submitted,

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HIGHWAY AND BRIDGE SURVEYS: LOCATION SURVEY[a]

Progress Report of the Committee on Highway and Bridge Surveys of the Surveying and Mapping Division
(Proc. Paper 1698)

INTRODUCTION

Purpose and Scope of Location Survey

The location survey fixes the proposed highway's centerline on the ground and includes the procurement of field data necessary for design and the acquisition of right of way. In a normal location survey, the alignment determined by the preliminary survey is staked out and a sufficient number of selected points on the centerline are referenced so that it can be re-established.

When conventional ground surveying methods have been used in the preliminary survey stage, much detailed information for design and right of way is obtained when the baseline is staked out. The staked baseline is used as a reference line for profile, cross-sections, topography, the location of existing property lines and other information that will be needed.

When large scale aerial photographs and maps made from them were used in the preliminary-survey determination of the final alignment and grades of the highway, part of the detailed information is obtained from them. Location-survey field work supplements the maps only as necessary to supply missing detail. In some cases it is possible to complete the construction plans and specifications, to write deed descriptions for right-of-way acquisition, and to let the contract for construction all in advance of actually staking the line on the ground.

The trend is toward more extensive use of aerial photography and photogrammetric maps in highway location. Thus the function of conventional ground methods in the location survey can be reduced essentially to the staking and referencing of the centerline and obtaining critical elevations, such as those of existing roads, railroads, and structures. Usually the large-scale aerial photography and photogrammetric map procured for the

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preliminary design also are used in obtaining much or all of the information needed for the final design, the preparation of construction plans and the other operations necessary in advancing the project to the construction stage.

An alternate method is to first stake the final alignment on the ground, signalizing the line at frequent intervals with muslin strips or lime, and then to take new aerial photographs at a relatively low altitude to produce a planimetric map at a scale of 1 in. = 50 ft. This map together with the low-level photography is used for final design, quantity computation, and the preparation of construction plans.

Electronic computers are further aids to efficient highway engineering. Profile and cross-section data can be obtained by reading spot elevations from the aerial photographs in a steroplotter. Then more savings can be effected by placing cross-sectional data on computer cards or tapes and applying them as direct input for developing earthwork quantities on an electronic computer.

The Location Survey

Requirements for the location survey are outlined in full below. As has been noted, in normal practice part of the requirements will have been met in earlier surveys.

Staking Centerline

The centerline established on the ground shall follow as closely as practicable the final line projected on the preliminary survey map, conforming to the major and minor control points and the alignment prescribed. Minor alterations and adjustments are permissible and desirable in best fitting the line to the terrain during the staking-out process. Modification also may be necessary as a result of incomplete or inaccurate preliminary survey information.

The centerline is staked out with reference to the preliminary traverse or baseline if conventional ground surveying methods were used in the preliminary survey, or with reference to the control traverse if aerial survey methods were used. In either case, this is accomplished by using scaled or computed offsets or ties to points of known position on the original baseline or control traverse. Centerline tangents are established on the ground, the intersection of each pair of adjacent tangents is determined and the deflection angle from the back tangent to the forward tangent is measured and checked for approximate agreement with the angle previously obtained in projecting the final line on the preliminary survey map. The measured deflection angles and the degrees of curve specified in the preliminary design are used to compute data necessary for running the curves as the staking of the centerline progresses. Where the intersection of tangents is inaccessible, the usual methods for determining the deflection angle are used.

Whenever possible the preliminary and location surveys should be referenced to a state plane coordinate system so that the final line can be established on the ground by using the coordinates of P.I.'s and the azimuths of tangents together with ties to the traverse control points. With reasonable care, third order accuracy should be obtainable. The specifications for third-order traverse are given in Chapter I.

Centerline stakes are placed at intervals of 100 ft and lined in with a transit. Stationing is carried forward continuously through curves and tangents with provision for station equations if and where they occur.

All points of curvature, points of tangency, and points at discrete intervals on long tangents should be carefully referenced to permit easy relocation of the line during all phases of construction.

Levels

Preliminary survey bench marks should be augmented by such additional bench marks as are necessary to provide them at a spacing of 1000 ft along the alignment of the highway and at a distance from the centerline sufficient to insure against disturbance during construction operations. In addition, at least one bench mark should be established within a reasonable distance (100-200 ft) of each proposed structure. The elevation and a complete description of each bench mark should be recorded.

Profile levels are taken along the centerline to obtain the elevation of the ground at each station and at all intermediate points where there is any significant change in the slope of the ground, in order to obtain a profile truly representative of the surface of the ground. For the design of adequate transition grades for connecting with existing roads or proposed improvements, the profile should extend at least 500 ft beyond the beginning and end points of the project.

When conventional ground methods are used in taking the profile, checks should be made on each bench mark as it is reached in progressing along the line, with a permissible tolerance of 0.01 ft.

Cross-sections likewise should be taken at each station, at intermediate points where there is a significant change in the slope of the ground, and for a reasonable distance beyond the beginning and end points of the project. Intermediate cross-sections should also be taken at culverts, driveways and intersecting roads. In moderately rough terrain, cross-sections are taken at intervals of 50 ft instead of 100 ft and in very rough terrain an interval of 25 ft may be advisable. Each cross-section should be aligned carefully at right angles to the centerline and should extend far enough on both sides of the centerline to provide adequate ground surface information for the designer and for quantity computations.

Where the large scale aerial photographs previously mentioned are available, both profile and cross-section data can be developed in the steroplotter. Accuracy is comparable to that obtained in ground surveys.

Utilities

The nature and location of all utilities within the area of the proposed improvement both above and below the ground surface should be determined and recorded. These will include water lines, gas lines, sanitary and storm sewers, conduits, drains, telegraph, telephone or power lines, railroads, traction lines, pumping stations and other utility appurtenances. Horizontal position normally is determined by station and perpendicular offset, right or left of centerline, measured to the nearest 0.5 ft. Elevations of underground utilities should also be obtained, generally to the nearest 0.1 ft. Complete information on utilities is important so that provision can be made for their rearrangement or relocation where necessary.

Property Corners and Property Lines

The position of all property corners, property lines, fences, buildings and other improvements must be accurately determined and recorded. This information provides the basis for determining right-of-way requirements, for writing deed descriptions, for appraisal, and for negotiating for right-of-way acquisition or easements. The names of all property owners where right-of-way acquisition or easement may be involved should also be obtained.

Where aerial methods are used, the locations of control-survey monuments can be arranged to permit ready computation of ties to property corners. In the method in which low-altitude photography is taken after the centerline is staked out, signalized points on the centerline serves a similar purpose.

Intersecting Roads

The direction of all intersecting roads with respect to the staked centerline should be measured and recorded. In addition, profiles and cross-sections of the intersecting roads should be taken for some distance on both sides of the centerline of the project, usually at least 1000 ft. It is preferable to have too many cross-sections than too few.

Where a rotary intersection or a grade separation is anticipated a special survey of the area is made for the detailed studies necessary for design and plan preparation (see "Special Site Surveys" below). More extensive topography and cross sectioning along the intersecting road is necessary in these cases.

Ditches and Streams

Ditches and streams within the area of the improvement should be carefully located with respect to the staked centerline. In addition, stream bed profiles should be taken for some distance up and down the stream; from one to two hundred feet on ditches or small streams may be adequate, whereas for larger streams a more extensive profile is necessary. Occasional cross-sections of the stream should also be taken to provide information for use by the designer in making hydraulic studies.

Detailed information should be obtained for existing culverts or bridges including the type, size, number of openings or spans, elevation of culvert flow lines or stream bed elevations under the bridge, and high water elevations where available.

Measurement of critical elevations at existing structures is one function that rarely can be performed by photogrammetry. The amount of ground survey necessary for such fill-in data is slight, however, and can be made a specific part of the instructions to field parties.

At any stream crossings along the staked centerline where a large culvert or bridge may be needed, a special survey of the area is made to provide the detailed information needed for the design and preparation of plans.

Special Site Surveys

In order to obtain the detailed information needed for the design of large culverts, bridges, interchanges and complex intersections at grade, special site surveys are made. Such surveys should be sufficiently detailed and complete to permit the designer to determine definitely the location, skew,

elevations and design of all parts of the structure. They can be made either by ground methods or by aerial methods supplemented by field measurements as may be necessary.

Information obtained should include alignment of the stream or intersecting road, topography, profiles, cross-sections, elevations of grade controlling points, foundation conditions, and in addition for bridges or large culverts, data on adjacent structures upstream and downstream including their waterway openings, high-water marks, and the drainage area.

Site surveys for borrow pits should provide information on quality and quantity of material, availability and accessibility. If the borrow pit is specified, ground surface elevations along lines perpendicular to one or more arbitary baselines may be taken for use in the later computation of the quantity of material removed.

Additional Operations

Location Immediately Prior to Construction

As stated previously when large scale aerial photography and maps made from them are used, it is possible in some cases to complete the plans and specifications and to let the contract for construction before actually staking the centerline on the ground. Under these conditions the line need not be staked out until the contractor is ready to begin construction and the location survey becomes a combined location and construction survey.

The centerline is staked and stationed as previously described. Reference hubs for points of curvature and tangency and for points on long tangents are established beyond construction limits. Clearing and grubbing stakes or flags are placed usually opposite full stations, using scaled distances from the centerline. After the area is cleared and grubbed or substantially so, slope stakes are set on both sides of the centerline opposite full stations and half-station points. These stakes may be located either by using computed or scaled offsets from centerline or by conventional ground surveying methods of slope-staking. In either case levels are run to determine the cut and fill figures to be marked on the stakes. If offset grade stakes are used instead of slope stakes, the procedure is similar except that a constant offset distance from centerline may be used.

In addition stakes are placed on the centerline of each culvert barrel or small bridge span, extended far enough from the ends of the structure so that they will not be disturbed during construction. Unless the stakes are driven to flow line grade, the vertical distances from their tops to the flow line extended should be determined, recorded and marked either on the stakes or on witness stakes. Headwall and wingwall alignment should be staked similarly. In all cases, the stakes should be referenced so that they can be readily reestablished.

Combined Preliminary and Location Surveys

Another variation of the location survey is sometimes used when the road runs through "easy" topography or follows an existing road. In cases of this kind, the staking out of the centerline follows the reconnaissance, and the location survey becomes a combined preliminary and location survey. The

locating engineer establishes the centerline on the ground as a direct location operation, eliminating entirely the preliminary survey map and line projection. The line and grade are developed as the survey progresses to best fit the terrain, curves are run in, the line is staked and stationed, and profiles and cross sections are taken. Minor adjustments of line and grade may be made in the office during the development of construction plans. This method, called "direct location" is not recommended except under the most favorable conditions.

Respectfully submitted

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Journal of the
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SURVEYING FOR RICHARD I. BONG AIR FORCE BASE[a]

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(Proc. Paper 1699)

ABSTRACT

The surveying problems encountered in the development of the Richard I. Bong Air Force Base although numerous were not of an unprecedented nature. Advance, overall coordinated planning based on a combination of new and old established surveying techniques, each supplementing the other, produced the desired results.

INTRODUCTION

On the 24th of May 1955, an article appeared in the Chicago Daily Tribune stating that "the U. S. Air Force is acquiring 4,000 acres of land at Kansasville, Wisconsin for installation there of a 1,500-man jet fighter interceptor Base." The article proceeded to explain the time schedule for the work, the size and length of the single runway and purpose of the new Air Base.

This was probably the first public pronouncement in connection with the construction of the Richard I. Bong Air Force Base.

If and when this installation is completed it will fulfill a promise made by Defense Department leaders more than five years ago. This promise was that the jet interceptors based at O'Hare Field northwest of Chicago for the last five years would be moved when civil airline traffic was diverted to it from the crowded Midway Airport, 55th Street and Cicero Avenue, in Chicago, Illinois.

It is understood that two years ago, the daily scheduled air traffic at Midway Field reached a figure of 1,200 movements. As a result, a number of

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a. Presented at the Chicago Convention of the Society, Feb. 1958.

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daily flights have been moved into O'Hare Field, irrespective of the presence of F-86D interceptor squadrons at the latter field. The airlines, however, have indicated that jets are incompatible fellow tenants and have agreed with the City of Chicago that the jet squadrons should be transferred elsewhere.

Since this paper was prepared, a number of changes are taking place. They are motivated by world conditions and national policy, and are far beyond the scope of this paper. It is well to remember that any reference made herein as to number and length of runways, and purpose of this Base can rapidly change.

Plate I shows the proposed site of the new air base. It is located in a rural area in southeastern Wisconsin, about 1-1/4 miles south of Kansasville, from which point its easterly boundary extends 3-1/4 miles south and its northerly and southerly boundaries extend in irregular lines 4-1/2 miles towards the west. Approximately 5,229 acres of the site are in Kenosha County and the remaining 190 acres are in Racine County. Kansasville is approximately 25 air miles south-southwest of Milwaukee, Wisconsin, about 57 air miles north-northwest of Chicago, Illinois and 15 miles inland from the west shore of Lake Michigan. Although Kansasville is identified as the village nearest the site, the proposed Base actually lies between Bristol, Salem and Kansasville.

These small communities located in a dairy farm area must expect an influx within two years, of at least 20,000 persons—the wives, children, and families of the Air Force ground and air crews detailed to the Base. There are not more than 5,000 persons now in all the immediate area.

Richard I. Bong Air Force Base is so named for a Wisconsin fighter pilot who downed a record score of Japanese planes in World War II.

A word about the character, topography, soil, and other physical characteristics of the site.

The general area is rolling farmland, some of which might be termed hilly. The primary agricultural activity is the production of grade "A" milk, interspersed with the raising of cattle, hogs, and poultry.

The topography of the Base area is generally rolling, with a differential of approximately 95 feet between the high and low points. Elevations range from 751 feet to about 846 feet above mean sea level.

The soils vary from friable silty clay loam, some muck land in low spots to good sandy loam. A small area near the westerly limits of the site is quite stony with a mixture of silt and clay loam over a clay subsoil. The principle soil of the area is classified as Carrington silty clay loam.

There is no irrigation practiced in the area. The northerly portion of the area drains to the north through an open ditch system, while the southerly part drains in a southerly direction, also through an open ditch system.

As a matter of interest, the construction of this Base will probably involve the moving of 14 million cubic yards of earth. This is equivalent to four square miles of earth, one yard deep. The runway pavement will be about 17 inches thick requiring approximately 500,000 cubic yards of concrete.

Preliminary Surveys

Initial planning and site selection for so large a project, depends to a major extent on whether or not the plan will fit existing topographical conditions. With this in mind the Air Force proceeded to have the area mapped by aerial photography. This produced a general type map to a scale of 1 inch

equals 400 feet and a 5 foot contour interval. In addition to topography, the map included such important physical features as roads, railroads, streams or ditches, fences, houses, and timbered areas. Key elevations—on contours, road intersections, bridges, low and high points were also indicated.

Horizontal position was referred to the Wisconsin State Plane Co-ordinate System, South Zone, Lambert Projection. Vertical position was referred to existing U. S. Coast and Geodetic Bench Marks which are on Mean Sea Level (1929 Adj.).

This general, reconnaissance type, topographic map was then used for:

1. Preliminary cost estimates.
2. Studies as to feasibility.
3. Preliminary location of the runway and its approach patterns.
4. Preliminary location of roads, utilities, and buildings.
5. By the Real Estate appraisers for a study of ownership lines, improvements, and minimum costs considering severance damage and for related Real Estate studies.
6. Preliminary subsurface explorations and analyses.
7. A study to decide which areas would be included in the detailed topographic maps.
8. Studying drainage, runoff problems.
9. Cut and fill studies and earthwork problems.

This preliminary topographic map was well within Map Accuracy Standards. It became especially useful in discussions with the different citizen groups in the community, including the local municipal officials. Displacement of a large group of property owners, requires extensive explanation and this type of map proved invaluable.

Detailed Topographical Surveys

Early in 1955, the services of the Architect-Engineer firm of Holabird & Root & Burgee were obtained for the design of 29 buildings for the new air Base.

In order to prepare the necessary plans and specifications, detailed topographical surveys became necessary. In this connection, the Architect-Engineer was instructed to perform the necessary survey work, a general description of which follows:

Scope

a. Establish horizontal control points and a north-south and east-west Grid System over the entire area. The Grid System to be tied-in to United States Coast and Geodetic Survey triangulation monuments.
b. Establish vertical control over the entire area. Vertical control to be tied-in to United States Coast and Geodetic Survey Bench Marks (Mean Sea Level 1929 Adjustment). A permanent type bench mark was required for approximately each 160 acres.
c. Establish perimeter property lines and furnish metes and bounds description for same. The perimeter property lines are predicated on approximately 4,990 acres in fee acquisition area.
d. Obtain topography required for approximately 3,950 acres.

e. Plot topography in pencil on 28" x 40" sheets, using a scale of 1 inch equals 100 feet, and one foot contour interval. Pencil tracing cloth was required.
f. Cross-section the single runway. The cross-sections to cover a width of 1,275 feet from the runway centerline on the taxiway side and a width of 375 feet on the non-taxiway side. Runway cross-sections to be plotted on standard 10 x 10 cross-section paper. Suggested scales were, vertical 1 inch equals 5 feet, horizontal 1 inch equals 50 feet. Cross-section sheets not to exceed 40 inches in length.
g. Baselines and the coordinate system to be executed within second order accuracy.
h. Prepare specifications as required for proper and adequate execution of surveys in connection with obtaining services of surveying organizations.
i. Obtain releases from the property owners where damage may result and obtain before and after photographs where required to substantiate claims.

Accuracies

Second order accuracy was specified for the basic vertical and horizontal control. Third order accuracy was specified for secondary and supplementary control. Selection of a contour interval was probably one of the most difficult decisions to make. Cost considerations, the relationship between map scale and map accuracy, and time elements, and the character of the proposed project were all carefully considered. At the time the survey was being planned the particular requirements for each section of the total area were vague due to soil and real estate uncertainties. The diversified construction which is inherently a part of so large a project was still in the discussion stage. The location of the main runway was uncertain due to the airway traffic pattern. The time schedule established was in the terms of Army terminology, a "crash schedule." As a matter of record the location of the runway was later modified, and thus the choice of 1 foot contours over the entire area was apparently a logical decision.

Vertical and Horizontal Control

There was but one choice for datums. The very nature of the installation, precluded all but Mean Sea Level (1929 Adjustment) for vertical control, and North American Datum (1927) for horizontal control.

This is a "must" in later establishing geodetic control for the runway navigational aid and landing systems.

Horizontal control was based on an accurate north and south baseline, three miles in length which was run along Highway Route 75, between Sections 3-4, 9-10, and 15-16. The baseline was tied into United States Coast and Geodetic Survey triangulation stations and a 1,000-foot Grid System was established over the entire area. Ten-inch boat spikes were set at all corners of the 1,000-foot intersections. The maximum permissible total angular error was specified to be 15 seconds times the square root of the number of instrument stations.

After the 1,000-foot grid system was established, 2-foot wood laths were set at all intermediate 100-foot stations on the grid system.

Survey Data

The topographical data required to fill in the skeleton grid included the following:

a. Location and elevation of all existing buildings, silos, windmills, roads, pavements, trees (4" or larger) and all other permanent structures, such as retaining walls, culverts, etc.
b. Location, elevation, description, and type of all overhead and underground utilities.

Supplementary Surveys

Although the detailed topographic maps were prepared by the Architect-Engineer, a number of supplementary surveys were required, and these were performed by the U. S. Army Engineer District, Chicago, Corps of Engineers.

Drainage Surveys

An off-Base drainage study of the entire area was made. This was accomplished by using the preliminary map that was prepared by aerial surveys. To provide adequate on-Base drainage, it was decided to improve the present off-Base ditch system by realigning, widening, and deepening. As the off-Base ditch system drains into the Fox River it was necessary to determine the extent of the deepening that could be accomplished, the limiting factor in any case being the differences in elevation. Five different ditches were involved varying in length from 10 to 14 miles. In order to plan and design this improvement, control traverses were run and new alignments were staked out in the field. Periodic triangulations into a church spire in New Munster, Wisconsin served as a horizontal check on these traverses which were tied-in to the Base coordinate system. Existing property lines were one of the principal governing factors in establishing the new ditch alignment. Sufficient cross-sections were then taken to facilitate the design.

Layout of Runway and Taxiway

After a number of studies, it was finally decided to have only one runway, which would also accommodate jet bombers of the Strategic Air Command. The runway would be approximately 12,000 feet in length and oriented on a NW-SE bearing. The increasing complexity of sky space over the entire United States renders the planning of the runway and approach patterns extremely important. The orientation of the runway had to be acceptable to all United States flying interests, both civilian and military.

Laying out the main runway centerline to its required bearing, also served as a check on the grid coordinate system. Every point that the centerline intersected the grid lines was tied-in to existing grid intersections. A straight line equation was computed for the centerline and the grid line intersections were computed by coordinates. The computed distances were then compared to the measured distances. These checked well with required accuracies.

It should be noted that due to convergence of meridians the bearing of the runway at the SE end would differ from the bearing at the NW end. In establishing the main runway orientation, the measurements were made at a point which at the present time is the mid-point of the runway.

The original north-south baseline that was laid out on Highway Route 75 was tied-in by Polaris observations to astronomic north and by triangulation to geodetic north. Although, the adjective "true" is used in both of these directions to distinguish them from magnetic directions, the word "true north" in this instance was used on the Polaris or astronomic determination.

Layout of Test Holes for Subsurface Explorations

Due to uncertainties as to soil conditions, a good many test holes were drilled in the area. These holes were staked out in the field by stadia methods and elevations were marked out on lath. There are extensive areas on the site covered by a soft, fibrous, organic type of soil, similar to peat bogs. Test borings had to be made to determine the thickness. These areas were mapped by the plane table method.

Glide Angle Surveys

In order to better understand the meaning of Glide Angle the following definitions are appropriate at this point.

Clear Zone

Clear zones are the areas immediately adjacent to the ends of a runway which have been cleared of all above-ground obstructions and graded to prevent damage to aircraft undershooting or overrunning the runway. The standard clear zone dimensions are 1,000 feet long (measured along the extended runway centerline) and 2,000 feet wide (1,000 feet on each side of the extended centerline.)

Approach Zone

The approach zone is an area beyond each clear zone, extending on the ground for a distance of 25,000 feet along and symmetrical about the extended centerline of the runway. The width of the approach zone at the end of the clear zone is 2,000 feet, flaring to 4,500 feet width at 10,000 feet from the end of the clear zone, and remaining 4,500 feet wide for the additional 15,000 feet.

Approach Surface

The approach surface is an imaginary plane covering the approach zone, beginning at the end of the clear zone at the elevation of the end of the runway and rising over the approach zone on a slope of 1 on 50 (known as the glide angle) for a horizontal distance of 10,000 feet. (200 feet above elevation of end of runway.) From this point the controlling elevation of the approach surface will remain at 200 feet until the end of the approach zone (25,000 feet from the end of the clear zone).

Transitional Surface

The transition surface joins the approach surface and landing area to the horizontal surface. It slopes upward and outward from the approach surface and from the boundary of the landing areas. The slope of these transitional surfaces, measured at right angles to the axis of the runway is 1 on 7. Transitional surfaces terminate at the intersection with the horizontal surface.

There are a number of other definitions that enter into the general picture, but for purposes of this paper, the above definitions are sufficient. Plate II shows in general what has been described above.

It is obvious that for safe and efficient aircraft operations, obstructions that exist on the areas described would have to be removed.

In order to determine the number and extent of these obstructions a glide angle survey was made on both the northwest and southeast ends of the runway. A map was prepared which included the following:

a. Five-foot contour intervals.
b. Obstructions which extended to within 10 feet or above the glide angle, or transition plane were indicated by numerical identification.
c. A summary of the obstructions showing in tabular form: (1) obstruction number, (2) tract number, (3) object, (4) top elevation, (5) maximum permissible elevation.
d. Tract boundaries, including tract number, ownership and acreages. Where severance damage occurred, both the portions acquired and portions remaining were shown.
e. Roads, railroads, pipelines, and utilities proposed for relocation.
f. A separate profile of the runway centerline (extended) to limit of proposed acquisition, showing graphically, relative elevations of original ground, angle of glide, and obstructions which exceed maximum permissible elevations, with their identifications.

The map was of major import in connection with real estate acquisition. Acquisition of title to obstructions and the land upon which these obstructions exist is the obvious method of securing their removal and preventing future replacement.

However, a more practicable approach on preventing the erection of hazardous structures in the approaches to runways is by acquisition of avigation easements, or rights in the air space over land upon which erection of obstructions appear probable. Many interesting problems have arisen in the preparation of legal descriptions for avigation easements, particularly, when one part of a parcel falls in the transition zone and part in the approach tract.

Concrete Monuments for Construction Control

Despite the fact that initial surveys furnished a good many permanent control points, it was realized that extensive construction operations would make these points very uncertain if not completely useless.

In order to have more positive control when construction begins, a line was run in parallel with and 1,000 feet southerly from the centerline of the northwest-southeast runway. At every point where this line intersects the grid lines a concrete monument was placed. A line of levels approximating first-order accuracy will be run in the future on these concrete monuments. A brass cap on the top of each concrete monument will give the elevation and the grid coordinates. These concrete monuments were placed well outside the construction areas and in comparatively sheltered sectors, so that vertical and horizontal control will be readily available when construction begins.

Surveys for Real Estate Acquisition

Following are the types of real estate acquisition required for Richard I. Bong Air Force Base:

a. Fee title to over 5,000 acres.
b. Clearance easements for over 500 acres.
c. Safety easements for over 300 acres.
d. Avigation easements.

e. Rights-of-way easements for relocation of roads, and utility lines.

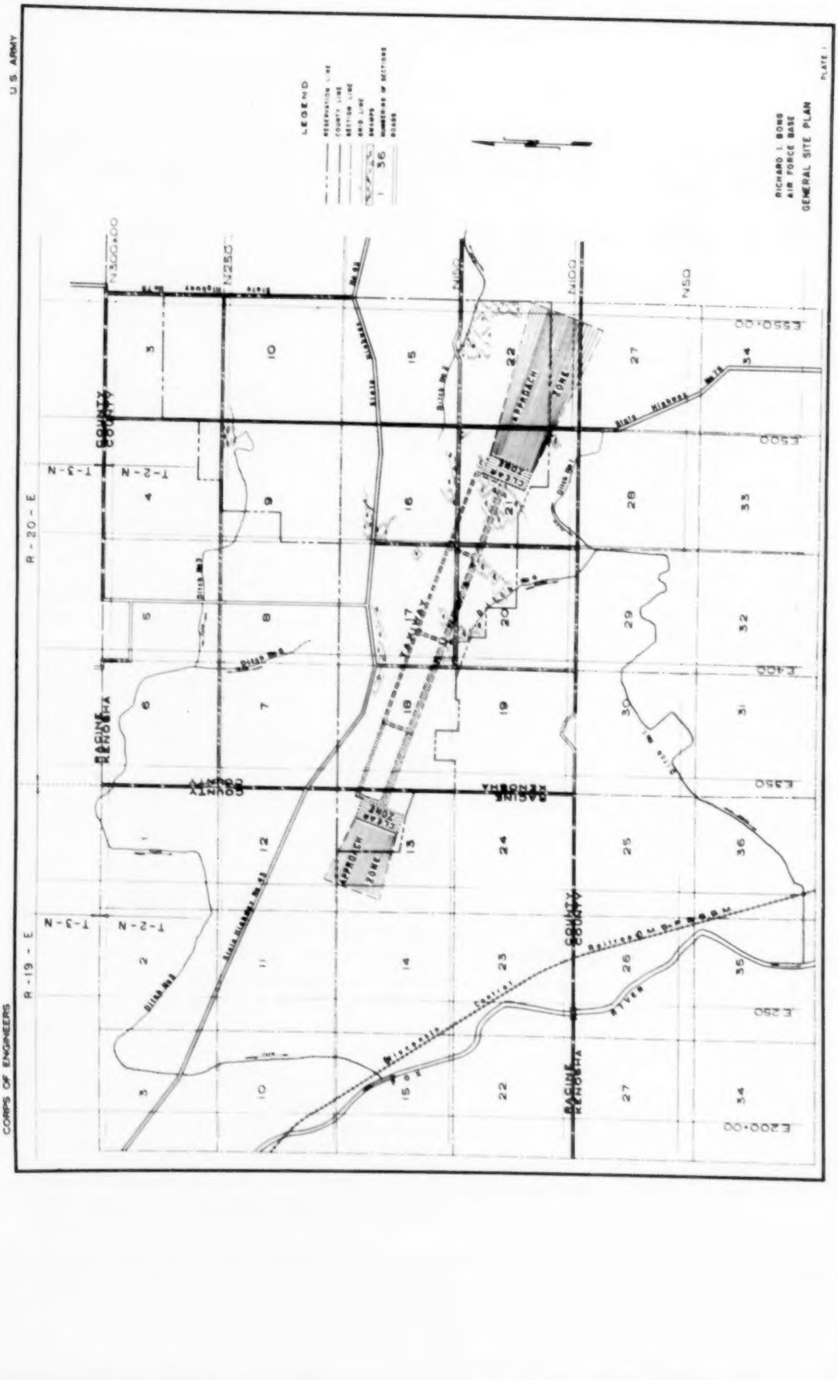
When the taking lines become more firm, they will be tied-in to existing property monuments. Tract maps and necessary legal descriptions will then be prepared.

CONCLUDING REMARKS

It should be noted that the survey work for this project was not accomplished by using just one method, but a combination of methods. One method supplemented the other. Photogrammetry, transit-stadia, and the plane table were all used, depending on the particular set of conditions.

The surveys were performed on privately-owned land, which has been under continuous cultivation, and control points were established on a day-to-day basis. Securing entry permits and keeping them current added to the problems. The farmers in the area have proved extremely cooperative under the circumstances.

Planning is proceeding for field surveys necessary during the construction phase, which, if present schedules are adhered to, will begin sometime in 1958.


U.S. ARMY
CORPS OF ENGINEERS
LEGEND
RICHARD I. BONG
AIR FORCE BASE
GENERAL SITE PLAN
PLATE 1
R-20-E
R-19-E
T-3-N
T-2-N
RACINE
KENOSHA
COUNTY
APPROACH ZONE
CLEAR ZONE
TAXIWAY
KENOSHA RIVER

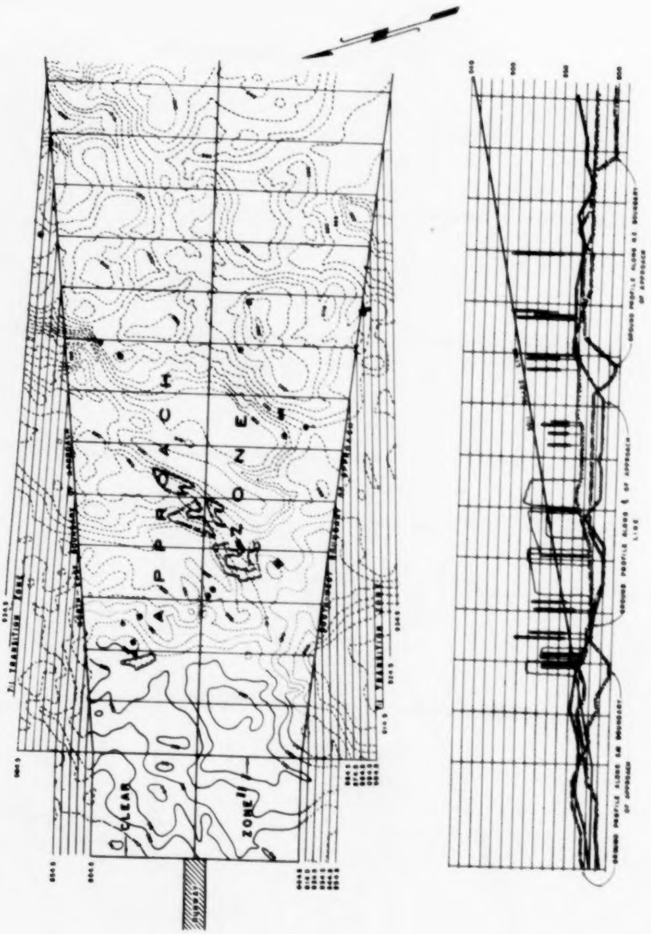


PLATE 2

Paper 1700 July, 1958 SU 2

Journal of the
SURVEYING AND MAPPING DIVISION
Proceedings of the American Society of Civil Engineers

PHOTOGRAMMETRIC DEVELOPMENTS FOR HIGHWAY ENGINEERING[1]

R. H. Sheik[2]
(Proc. Paper 1700)

Aerial photogrammetry has generally been accepted as an accurate and efficient tool for highway engineering and its integration with the electronic computer has increased the usefulness of both. There is a concerted effort to develop new techniques and applications of these tools and as a result the fullest use of the photos is not being made. There is a tendency to wait until maps and other products are prepared before attempting to study location. It should be remembered that considerable time and money can be saved in location of route by use of photogrammetric mapping if a careful study is made of the aerial photos with the stereoscope by an engineer trained in this technique. Noticeable progress has been made in gaining the confidence of the engineer, contractor, and general public in aerial photogrammetry. To maintain this progress, the engineer and the aerial photogrammetric contractor must insist on accuracy. This desired accuracy can readily be obtained by having (sufficient) accurate control, capable photogrammetrists, good equipment, and working within the capability of the instruments.

Photography

The first essential of aerial photogrammetry is good aerial photography which is influenced by many factors such as airplanes, cameras, films, etc.

Airplanes are available that will accommodate the necessary photographic equipment, fly the desired altitude, maintain the speed and stability necessary for photography and still have the speed to reach the site quickly. Further reduction in flying speed for low level photography is desired.

Note: Discussion open until December 1, 1958. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1700 is part of the copyrighted Journal of the Surveying and Mapping Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. SU 2, July, 1958.

1. Paper presented before a joint meeting of the Highway Division and the Surveying and Mapping Division, A.S.C.E., Chicago Convention, February, 1958.
2. Engr., Bureau of Location and Design, Ohio Dept. of Highways, Columbus, Ohio.

Aerial cameras have been improved so that quality photography can be obtained. They have distortion free lenses and high speed shutters. These have aided in obtaining photography when light is not at its best and in reducing the blur caused by image motion.

Aerial topographic film has excellent quality but faster film is desired particularly in winter months when the light is of low intensity. Progress is being made in this field and no doubt better film will be available in the future.

The most recent and important development for the improvement of quality and production of photography in the laboratory is the automatic dodging instrument. They provide a more uniform density in the prints and diapositives for the photogrammetric plotter. Two such instruments are available. They are the Logetronic Printer and the Fluoro-Dodge.

All of these improvements are very important to the highway engineer as they increase the accuracy of aerial photogrammetry and also reduce the cost by saving time in plotting and correcting survey errors after project reaches design stage.

Ground Control

The next phase of aerial photogrammetry that greatly affects accuracy and cost is obtaining the necessary ground control. Progress has been made in reducing the necessary control and increasing its quality. Two instruments, the tellurometer and geodemeter have been developed to reduce time and labor in measuring distances. These instruments are very accurate and are proving to be very helpful in establishing horizontal control.

The bridging method is used to obtain control for projects of considerable length or those where terrain is exceedingly rugged. This is done by establishing horizontal and vertical control at each end and if possible the middle of the project by ground survey methods. The stereo models are then placed in a first order photogrammetric plotting instrument and the established control extended through the project checking on the known points. The instrument coordinates are then adjusted by the electronic computer to an acceptable accuracy.

It is also desirable to have signals placed on property lines and section lines with which you are concerned to assist in the preparation of the right-of-way plan by photogrammetric methods.

Various computations such as the traverse, solar observation adjustments, etc., can be performed quickly on the electronic computer.

Location Mapping

After the high altitude photography has been made available it should be carefully studied and the feasible locations limited to one or more corridors. The width of the desired map for each corridor can be determined from the photos.

The topographic map, usually at a scale 1'' = 200' with 5' contours, compiled by means of the photogrammetric plotter provides the engineer with a visual model to pin-point the proposed center line of the project. This map is also useful in the design and construction stages to study drainage, right-of-way and to locate the proposed line on the ground.

Cross section information at definite break points of the ground can now be obtained from the topo map for each line being considered. This information, with the station and elevation of the point of intersection of the grade lines, length of vertical curves and typical section data is sent to the electronic computer laboratory. The computer will then determine earthwork quantities and also determine slope intersections for right-of-way analysis.

The so-called "digital terrain model" principal is being developed by the Massachusetts Institute of Technology. This is the presentation of the three dimension data in digital form so that it can be used by the electronic computer. It is claimed that this system will permit the evaluation of many locations across the model nearly as quickly as one. The digital information can be obtained from the contour map or taken directly from the stereo plotter to punch cards or tape.

Progress is being made in the development of an automatic or semi-automatic stereo plotter. It is understood that one of these is to scan the entire model and draw the contours and another is to automatically adjust the instrument as to elevation for the various locations chosen by the operator. Other instruments are being developed for use with the Kelsh stereo plotter that will permit direct printing or recording on cards or tape the X,Y,Z coordinates. When these instruments become proficient they will expedite photogrammetric mapping and increase its accuracy.

Design

Maps and terrain information obtained by photogrammetric methods must be more accurate for design than for location studies; therefore larger scale photography is required. This is generally taken at an altitude to provide maps at scale 1" = 50'. Prior to exposing this photography the center line should be staked wherever it is feasible to do so and signalized to become a part of the ground control. From this photography planimetric maps, scale 1" = 50', are compiled by the stereo plotter to be traced on cloth or reproduced photographically as line sheets for the construction plans.

Site plans, scale 1" = 50' for structures and interchanges are produced from this photography. The scale can then be changed in the photo laboratory as desired, usually 1" = 20'.

Cross section information is taken from the same models before they are removed from the plotter. The elevation and offset of various breaks of the ground line on the desired station are determined and recorded by the operator.

An instrument was developed by the Battelle Memorial Institute as a research project for the Ohio Department of Highways for use with the Kelsh stereo plotter to obtain cross section information and record it automatically on punch cards. The offset distance and elevation is recorded to the nearest 0.1 foot. Prior to development of this instrument the point of reading was indicated on the manuscript and the elevation recorded with it by the plotter operator. The offset distance was then scaled and read along with the elevation to a draftsman plotting the cross section. This instrument is now in operation and has proven to be satisfactory. Other similar instruments can now be obtained that will record directly on cards or tape the terrain information obtained from stereo plotters.

The punch cards and design information such as grades, rate of super-elevation and typical sections are sent to the Electronic Computer Laboratory from which the design engineer obtains earthwork quantities, super-elevation tables, grade elevations as desired, slope intersections and coordinates of the cross sections.

There is considerable difference of opinion as to how many, if any, cross sections should actually be drawn or included in the construction plans, since the printed information is available from the electronic computer. This is due mostly to the drudgery and time consumed in drawing the sections. Thus the main objection to the use of cross sections will be eliminated by the use of line plotters and no doubt the practice will be to continue their use with probably a reduction of the number of sections included in the plan.

Recently developed line plotters suitable for drawing cross sections from cards or tape are now available from at least two companies. Electronic Associates and Benson Lehner Company. The size that appears to be the most desirable has a plotting area 30" x 30". This permits plotting at scales normally used on sheets of same size generally used in construction plans. The drawing is made in ink and the time consumed for a normal section of a four lane divided highway is approximately two minutes.

The Electronic Associates Incorporated have advised that they can furnish a line plotter that will plot on continuous roll paper which will advance automatically. It will also print the station number and the elevations of the center line. This makes the machine semi-automatic. It can be located in the computer laboratory and fed a stack of cards or tape with necessary work being performed by regularly employed machine operators in the laboratory. These improvements are modifications that can be attached to plotters already in operation. These instruments can be used for many plotting operations other than cross sections such as mass diagrams, work limits, etc.

These methods provide the designer with photography, a topographic map, line sheets, cross sections, computed grade line, super-elevation tables, earthwork quantities, and slope intersection information with the very minimum of engineering man power.

During design the special conditions (those other than typical) can be noted on modification forms and sent to the computer laboratory for computation of earthwork quantities to be used in the construction plans.

After completion of construction the final cross sections can be taken by aerial photogrammetry and final pay quantities computed by the electronic computer. The only ground survey work required is location of stations on center line and placing signals on those required for control. The elevations are known from the plan and the wing control can be taken from the photography used in design. This final photography can be taken at any season as the area has been cleared during construction. Besides being an efficient and expedient method of obtaining quantities for final payment, the photography is valuable as a pictorial record of the completed project.

There are many research projects in photogrammetry in other fields particularly for the military, and some of these may be adapted in the future to highway engineering.

There will be many improvements in photogrammetric instruments and no doubt some entirely new ones will be developed for highway engineering. There will also be many new applications of aerial photogrammetry to highway engineering. The rapidity with which these instruments and techniques are developed is contingent in a large measure on continued accuracy in aerial photogrammetric work.

Paper 1713 July, 1958 SU 2

Journal of the
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Proceedings of the American Society of Civil Engineers

HIGHWAY AND BRIDGE SURVEYS: INTRODUCTION TO BRIDGE SURVEYS AND RECONNAISSANCE SURVEY[a]

Progress Report of the Committee on Highway and Bridge Surveys of the Surveying and Mapping Division
(Proc. Paper 1713)

INTRODUCTION

Prior to the middle of the 19th century the surveys for most over-water crossings were conducted in substantially the same manner as those for other kinds of civil engineering construction. As a result there was little development of the literature of bridge surveying. However, the greater magnitude and increasing complexity of the progressively longer span structures of the late nineteenth and early twentieth centuries made mandatory the use of more accurate construction controls and led to the use of special surveying procedures and precision equipment.

As the importance of high quality surveys for large bridges became a significant concern of the civil engineer, further advancements took place in the design and execution of such surveys in order to secure the means for positively assuring the satisfactory horizontal and vertical positioning of all elements of the structure. In view of the spectacular increase in the number and length of highway bridges in recent years, an expanded national highway construction program, and the unique character of surveys for large bridges, it has seemed essential to make more easily available to the profession the latest information on this subject. This is the purpose of Part B.

Surveys for large bridges, like those for other major transportation projects, are executed in three phases, viz., (1) The Reconnaissance Survey, (2) The Preliminary Survey, and (3) The Location Survey.

The Reconnaissance Survey is executed to procure the basic information needed for preliminary project planning and other initial studies. It is primarily concerned with the selection of various project sites and the first appraisal of their feasibilities. Field surveys are seldom required at this stage

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a. This paper will form the basis for a chapter in a proposed ASCE Manual of Engineering Practice.

of the investigation. Most of the information required for the reconnaissance study and report usually can be obtained from existing maps, aerial photographs, and boring records. However, it may be desirable to inspect the sites and make preliminary traffic counts. In circumstances where the minimum desired foundation information is not available, it may become necessary to make a cursory foundation exploration, ordinarily consisting of wash borings with a few undisturbed samples at critical locations.

The Preliminary Survey consists of a series of field operations which are begun after the location of the bridge has been selected and its approximate alignment determined. The principal objective of the Preliminary Survey is to obtain the physical data needed for the design of the project and for the acquisition of all rights-of-way. The operations usually include: preliminary triangulation to establish the starting coordinates for traverses at the bridge heads and along the approaches, topographic surveys along these traverses, and the design of a more elaborate triangulation system which will serve later during the construction phase of the project.

In addition to the foregoing operations associated with the surface features, the Preliminary Survey also includes the hydrographic survey of the project site, special geologic investigations and foundation explorations, and the preparation of special maps that must accompany applications for construction permits from the various federal, state, and local regulatory agencies.

The Location Survey program frequently consists of two stages, the Preconstruction Survey and the Construction Survey. The Preconstruction Survey operations are performed in advance of the actual construction but are directly related to it. Examples are the establishment of the horizontal control stations and bench marks that will constitute the fundamental framework for defining project lines and grades. Much of this work can be done during the Preliminary Survey but generally some refinement and strengthening is necessary to improve its accuracy.

The Construction Survey operations provide the immediate and final positioning, both horizontally and vertically, of the various components of the bridge structure. The results of these operations must be of such accuracy as to preclude any errors of fit as due exclusively to survey control. Also, these operations must be closely coordinated with the construction schedule to avoid unnecessary and costly delays for the contractor.

Although the Construction Survey network may be tied to the federal systems of horizontal and vertical control, it usually possesses intrinsically a higher order of internal consistency and accuracy than the federal schemes and is, therefore, not adjusted in a subordinate manner to them. It should be noted that ordinarily a state plane coordinate system should not be used as a basis for bridge surveys. Such systems are based on sea level distances and are variable in scale. The most logical choice is a local coordinate system based on the mean elevation of the bridge.

For bridges several thousand feet in length surveys having an accuracy of one part of 100,000 may be required. Special geodetic equipment and experienced personnel will be needed.

The importance of attaining high accuracy in the Construction Survey cannot be overemphasized. Present engineering design and erection practices frequently permit only the smallest dimensional tolerances. The control of surveying errors to within these specified tolerances requires constant vigilance and competent engineering organization if wasteful delays and the needless expenditures of funds are to be avoided.

Chapter V. RECONNAISSANCE SURVEY

1. Introduction

Purpose and Scope of Reconnaissance Survey

The Reconnaissance Survey for a major water crossing structure serves basically to obtain information affecting the following three engineering studies: (1) the location of all possible routes, (2) their comparison with respect to feasibility, and (3) the preparation of preliminary estimates of the cost of construction.

2. Conduct of Reconnaissance

Study of Available Data

Much of the information and data for the reconnaissance study can be obtained from various local, state, and federal agencies that are broadly concerned with the administration of navigable waters and particularly with engineering works and navigation therein. These agencies include the U. S. Corps of Engineers, U. S. Geological Survey, U. S. Coast and Geodetic Survey, U. S. Coast Guard, and numerous harbor commissions and port authorities.

Frequently these bodies will be able to provide some type of map coverage of the various potential route locations. Such cartographic information may be in the form of topographic, highway, and geologic maps. Hydrographic charts, special maps as of cable crossing locations and aerial photographs may be available.

Other valuable and pertinent information may consist of tide and current tables, records of harbor and river soundings, and digests of the laws and regulations which pertain to construction in harbors, rivers, and other navigable waters. Permits for construction of the project will be required from the U. S. Corps of Engineers and possibly other agencies and the detailed requirements for processing these should be obtained during the Reconnaissance.

New Aerial Photography

When the available data are insufficient for the reconnaissance study, it is necessary to obtain whatever new information may be needed. One of the most convenient means for gathering part of such information is by aerial photography. Both vertical and oblique photographs will provide much useful data. The cost of such photography will be modest and the results adequate for reconnaissance purposes.

In the total absence of surface information, it may be necessary to prepare large-scale topographic maps of the location or locations under consideration. This situation, however, is not commonly encountered.

Engineering Survey

A field inspection should be made of the proposed alignment for the bridge and its approaches to record any unusual features such as existing structures, pipe and cable locations, and drainage facilities which must be considered in the design of the crossing.

The field survey will include the gathering and evaluation of general geological and foundation information. If a more detailed study is desired at this stage, it may be necessary to undertake a limited boring program or drive a few test piles. General topographic and soils information will be required along both approach locations. Such data are necessary for analyzing the feasibility of the proposed project and estimating the cost of construction.

Before any boring or sampling program is begun, a thorough search for previous findings should be made. Sometimes, there will have been prior investigations in the areas under consideration. An example of such a situation is represented by the early studies in 1924-26 along the route of the present Richmond-San Rafael Bridge in California. While this foundation investigation was not made along the final line selected for the project, the information was valuable in determining the location of the various strata and the approximate depth to which pier excavation could extend.

Traffic Survey

The Traffic Survey is an important phase of the reconnaissance but will not be discussed here because the details are beyond the scope of this manual. It is usually conducted in the early stages of planning a major bridge structure. The purpose of the traffic survey is to determine the route which best serves the traveling public, to help establish the feasibility of the proposed project and to estimate with reasonable accuracy the magnitude of future increases of traffic over specific routes.

3. Reconnaissance Report

From a study of the information from all available sources, including new aerial photography and field and traffic surveys, the feasibility of the proposed project can be evaluated. The predicted benefits to be accrued from the new facility must be weighed against the estimated construction costs and the ramifications of financing these costs. The detailed approach and evaluation of the many aspects of the total problem are not germane to this manual. It is sufficient to state here that the reconnaissance survey for the proposed bridge crossing is often a very important phase in its development and the reconnaissance report generally exerts considerable influence on the ultimate engineering design of the new facility.

The outline of a typical reconnaissance report is as follows:

I. SUMMARY (Conclusions and Recommendations)

II. REPORT

- A. Introduction
    1. Scope
    2. Previous Bridge Studies
    3. Present Problem
    4. Permits
- B. Crossing Studies
    1. Crossing plans
    2. Foundation Investigations
    3. Surveys

B. Crossing Studies (continued)

4. Cost Estimates
5. Legal

C. Traffic and Revenue

1. Traffic
2. Revenue
3. Financing

Respectfully submitted

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PRECISE SURVEYS FOR MACKINAC BRIDGE*

R. M. Boynton**
(Proc. Paper 1716)

ABSTRACT

A brief description is given of the magnitude of the project and the surveying problems involved. Equipment and methods used to establish a major triangulation net on land; a minor triangulation net of six sea towers for locating piers; and vertical control across approximately four miles of water is described.

The Mackinac Bridge, spanning Mackinac Straits which connects Lake Michigan on the west with Lake Huron on the east, links the so-called lower peninsula with the upper peninsula of Michigan. It is located about 50 miles south of the famous Sault Locks at Sault St. Marie and serves as a gateway to the north and Pacific Northwest of the United States and Canada.

The Mackinac Bridge, with its approaches, is 26,372 feet (5 miles) in length and crosses approximately four miles of open water. The over-all length of the bridge, between abutments, is 19,243 feet and features a suspension bridge with a main span of 3,800 ft. — the world's second longest; two side spans of 1800 ft. each — the world's longest; and a length of 8,614 ft. including anchorages — also the world's longest. Supporting the suspension bridge are two steel towers rising to a height of 552 feet above water. The south tower pier was sunk to a depth of 210 feet below water making the total height of this tower 762 feet above the base of pier. This is equivalent to the height of a 63-story building. The main cables have a diameter of 24-1/2" and are composed of 12,580 wires each. The length of the individual wires in the two main cables is 42,000 miles.

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The bridge carries four traffic lanes, a 2-foot median strip, and two 3-foot walkways. On the suspension spans the two outside lanes are 12 feet wide, supported on concrete-filled grating surfaced with asphaltic concrete. The two interior lanes are 11 feet wide, supported on 5" open steel grating. On the approach—truss spans, lanes are of the same width but they are supported on conventional concrete slabs.

Actual construction was started in May 1954. The bridge was completed within the budget and opened to traffic on November 1, 1957, the date originally set for the opening about four years previously.

The above figures on the magnitude and location of the project give some idea of the surveying problems involved in locating, with first-order precision, each of the 34 water piers, some in depths of water up to 140 feet, and all the other various component parts of the structure which make up its total weight of 1,024,500 tons.

Reconnaissance Survey

The Michigan State Highway Department had made quite extensive surveys in the area in the past in connection with bridge studies and the construction of the mole on the St. Ignace approach but unfortunately most of their data had been lost in a fire. All available information was collected from them, the U. S. Coast and Geodetic Survey, and the U. S. Lake Survey. A reconnaissance survey was made in February 1954, and despite 22 inches of snow, several triangulation stations were later recovered and tied into the major net. Even when the main survey party arrived on March 6, 1954, much of the area was covered with snow, the Straits were frozen over and recovery of bench marks and triangulation stations was difficult.

Major Triangulation Net

A major land triangulation net was established using three previously established stations and five new stations. (See Fig. 1) The three old stations were Mackinac West Base (U.S.L.S. 1852); D St. Ignace (U.S.L.S. 1851) and Green (U.S.L.S. 1926). The distance between Mackinac West Base and D St. Ignace was very strong because it lay directly in the first triangle which had one side as the original baseline on the Southern Peninsula (1852). However, as there was some question concerning the accuracy of the baseline itself (surveyed more than 100 years ago), a new 10,858.443 ft. base line was established along U. S. 2 in St. Ignace.

The new base line was measured with the use of chaining bucks with copper scribe plates. It was measured in sections with three separate 100-meter Lovar tapes. The line was then measured again using a different tape for each section. Temperature and tension readings were made with the measurement of each length. After running levels over all the bucks to determine the inclination corrections, computers figured all necessary corrections and analyzed the results. The two runs checked well within first-order limits.

As an additional check on the accuracy of the triangulation, a second base line between A-2 and M was measured with first-order accuracy. This base line, extending along the mole and located on the bridge centerline, had a length of 3,769.844 feet.

Seven Bilby steel towers and one latticed tower were erected at the eight triangulation points. They varied in height from 15 feet at Point M to 77 feet

at St. Ignace East Base. These heights refer to instrument elevations with the lights located ten feet higher.

Much of the triangulation work was performed in the evening or at night to permit the use of lights and to eliminate excessive refraction. At occupied stations all angles were turned a minimum of 32 times. Only Wild T-3 precision theodolites were used on this work. The average error of closure for the triangulation of the major net was 1.04 sec. This work, started on March 6, 1954 when the main survey party arrived at the site, was completed on June 15, 1954.

The new base line and triangulation net proved that the original base line measurement on the Southern Peninsula (1852) was accurate, but that slight changes were required in the coordinate values of Station Green.

To simplify computations, a local bridge system of coordinates was established, with the y-axis parallel to the bridge centerline (y = 10,000) and the x-axis through Point A-1, Bridge Station 0 + 00 (x = 20,000).

Minor Triangulation Net

To facilitate location of the 34 piers, a minor net of six sea towers was established. Three towers were placed on each of the 2,000 ft. offset lines, three east and three west of the bridge centerline. The longitudinal locations were carefully chosen to produce the best angles for cutting in each of the piers. The selection of locations was also influenced by the depth of water which varied between 26 and 93 feet at the adopted locations.

The sea towers were specially designed for the project as a single unit and not conventional tower-within-a-tower design. They were also designed for removal at the end of the 1954 season and re-establishment for the 1955 season since it was not practicable or economical to design them to resist ice pressure. Prefabricated units consisting of 18 inch pipe for the three legs and 4 to 6 inch pipe bracing were set on the Straits bottom with derricks and then secured with 10 inch steel piles driven inside of the pipe legs to firm bearing. The space between the pile and pipe leg was then filled with sand for additional rigidity.

The above type of tower had very little vibration and proved to be entirely satisfactory. One desirable improvement would have been provision of a separate landing platform. At times of rough weather it was difficult and somewhat hazardous to transfer heavily laden men from a tossing boat without bumping against a tower leg.

Establishing Pier Locations

Stalls for holding the caissons in position during sinking and frames for cofferdams were fabricated at a dock in St. Ignace, loaded on barges and towed to the various pier sites for placement by floating derricks. Before leaving the dock, four points on each frame were accurately located and marked for use in spotting the frame. After selecting the two sea towers best located for the purpose, the coordinates and azimuths of these points were computed for the frame in correct position. After the frame reached its approximate location, sight poles were attached at the previously determined points. The Contractor then maneuvered the frame into position until the two sight poles used by each of two observers were in perfect alignment. Spur piles were then dropped through special attachments to the frame and driven into the overburden to hold the frame in position.

During these operations and during the sinking of caissons and the driving of sheeting, almost continuous check readings were made so that deviations from specified alignment could be detected and corrected. When work was being rushed on a 24-hour a day basis, a special system of pulsating lights was used on the sight-poles to distinguish them from the maze of other lights on the marine equipment hovering around the pier site.

The final precise stationing for the piers, after they were completed above water, was established by triangulation from the water towers. As an additional check, thirteen spans were also measured directly with a specially calibrated 500-foot tape. This tape was calibrated on shore in such a manner that sag and tension corrections were eliminated, with correction for variations in temperature the sole variation from the direct measurement. These check measurements indicated absolute relative accuracy in span lengths between piers in many cases; and in one span only did a maximum variation of slightly less than one-half inch occur.

Vertical Control

The southern and northern peninsulas had never been linked by a direct run of precise levels. This was first accomplished in 1955, using piers 4, 7, 17, 19, 20, and 22 as stepping stones. The method employed was one of reciprocal precise leveling designed to compensate for the earth curvature and refraction effects, and known as the "river crossing" method. Despite the fact that two of the steps or legs exceeded 3200 feet in length, first-order accuracy was obtained and the levels closed within 0.007 ft. These levels indicated a difference of 0.012 ft. between previously established benches on the two sides of the Straits.

From the above precise bench marks final vertical control points were set on brass plugs on each pier. Four brass plug control points were set on the bases of each of the anchorage piers, Nos. 17 and 22, one at each corner of each pier. Differential level readings taken during subsequent construction of the piers, cables and suspended structure in 1956 and 1957 indicated a very minor uneven settlement or tipping of the anchorages of about 1/8 inch. Additional computations however indicate that most, if not all, of this differential settlement between heel and toe of the anchorages is actually elastic deformation of the concrete base which is approximately 100 feet high between rock foundation and location of bench marks 10 feet above water. Since the anchorages are designed to resist a cable pull of 30,000 tons, they initially tend to tip shoreward with maximum compression at the heel. When the cable pull is subsequently added, they tend to tip toward midspan, with maximum compression at the toe. The resulting changes in elevations at toe and heel due to elastic deformation of the concrete base, including some slight elastic deformations of the supporting rock below, are often misinterpreted to be actual settlement of the foundation.

Since the main cables are spun in their unloaded position, actually 27.87 feet above their final full dead load position at center of main span, the sag of the initial guide wires must be set with extreme accuracy. The low point of the guide wire was measured with a Wild T-2 transit set inside of the tower with an un-obstructed line of sight somewhat below the catwalk and through a temporary opening to a target on the opposite tower. Readings. were taken on an inverted level rod which was hung through the catwalk. These readings were taken at night to minimize the difference between air

and wire temperature. The importance of temperature of the wire is indicated by the fact that, in the completed structure, each change of one degree Fahrenheit raises or lowers the elevation of roadway at midspan by one inch. Thus the suspended structure at midspan becomes a moveable bridge, powered by the effect of temperature, rising five feet above normal when the temperature falls 60 degrees — and lowering five feet below normal when the temperature rises 60 degrees.

When the first of the 37 strands of 340 wires of each cable was completed, it was also adjusted to specified sag by use of jacks and adjusting links at the anchorages. Its final sag was measured in the same manner as the initial guide wire. Subsequent strands were adjusted to proper sag by direct measurements to the initial strand. These adjustments and measurements were made at night when all wires would be of the same temperature.

The sag of each completed, compacted and wrapped cable is the average sag of its 37 strands and of the 12,580 wires of which it is composed. As the dead load of the suspended structure was added, the two cables at midspan came down to their calculated position within a tolerance of less than one inch.

Communications

Continuous communication between field office and all personnel was provided by radio. A base station was established in the St. Ignace field office. Four portable radios, furnished by the Michigan Bell Telephone Company, were assigned to parties in the field and at various observation towers. The magnitude of the project, great distances involved, time-consuming travel between isolated water stations, hazards inherent in manning the isolated water towers and the necessity for giving immediate and continuing instructions to the contractor while setting cofferdam frames, etc., made the use of radio communications not only essential but economical as well.

A 37 ft. boat powered by a 160-hp diesel engine furnished transportation on the Straits. Two station wagons and a truck were used for land transportation.

Special Equipment

The specified first order accuracy in locating piers required the use of special equipment, much of it considered standard for projects of this magnitude. Major items of equipment included Wild T-2 and T-3 theodolites; U.S.C.G.S. precise levels; Wild N-2 levels; and Lovar and Invar tapes specially calibrated by the U.S. Bureau of Standards. Also used were collimators, signal lamps, O-tents, ground tents, Bilby towers and Lovar and Invar level rods.

A straddle target, patterned after one in use by the U.S.C. & G.S. but not available on the market, was constructed for this project. It consisted of two light boxes accurately mounted on a rigid calibrated base, and was used for accurately establishing intermediate points on the true centerline of bridge over an unbroken length of four miles.

Five points on the bridge centerline, at A-1, M, A-2, Pier 17 and Pier 22, were previously established by triangulation. While direct shots between some of these stations could be used for establishing a centerline point on some newly constructed piers, intervening construction or equipment or unsuitable weather usually made this impossible. Where use of the straddle target was

required, it was set approximately to straddle the centerline. An observer with transit located elsewhere on the centerline turned sets of angles from one light box to a backsight target set on a previously established centerline point, and from that point to the second light box. The procedure was repeated for a slightly different transverse position of the straddle target. The centerline of straddle target, for each position, was scribed on the pier. The true position of the bridge centerline was then calculated from the observed angles, the spacing of the light boxes and the known distance from observer to straddle target. The true centerline was then located directly from the previously placed scribe marks and established on a brass plug set in the pier.

The G. Edwin Pidcock Company, Allentown, Pa., were engaged to do all of the surveying work required during the two first construction seasons of 1954 and 1955, under the general direction of D. B. Steinman's Resident Engineer, John W. Kinney. During this period the triangulation nets were established; all of the water piers were founded and most of them substantially completed; the two main towers of the suspension bridge were erected; and the two back-stay spans were floated into position. During this period the survey force generally consisted of a resident engineer, four observer, two recorders, two light keepers, a computer, one party chief, one instrument man and two rodmen. Subsequent surveys during 1956 and 1957 were performed by D. B. Steinman's own personnel.

The bridge was built for the Mackinac Bridge Authority, Prentiss M. Brown, Chariman. D. B. Steinman, M. ASCE, Consulting Engineer, was retained by the Authority for design and supervision of construction.

The author was in charge of the design and office supervision of construction of the substructure and main towers for D. B. Steinman. Since this portion of the work involved all the surveying during the first two construction seasons, he was also responsible for the office supervision of such work.

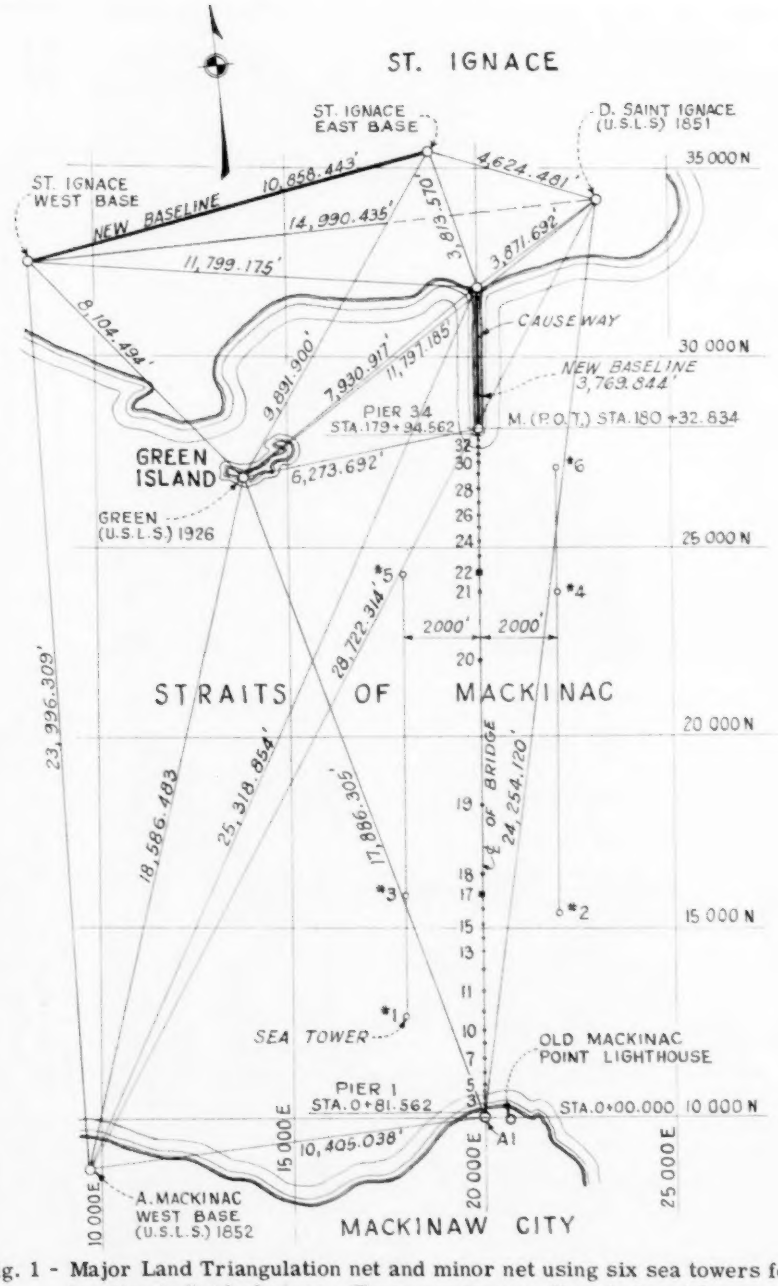

Fig. 1 - Major Land Triangulation net and minor net using six sea towers for locating individual piers. Three sea towers, Nos. 1, 3 and 5 are 2000 feet west of bridge while Nos. 2, 4 and 6 are 2000 feet east of bridge line.

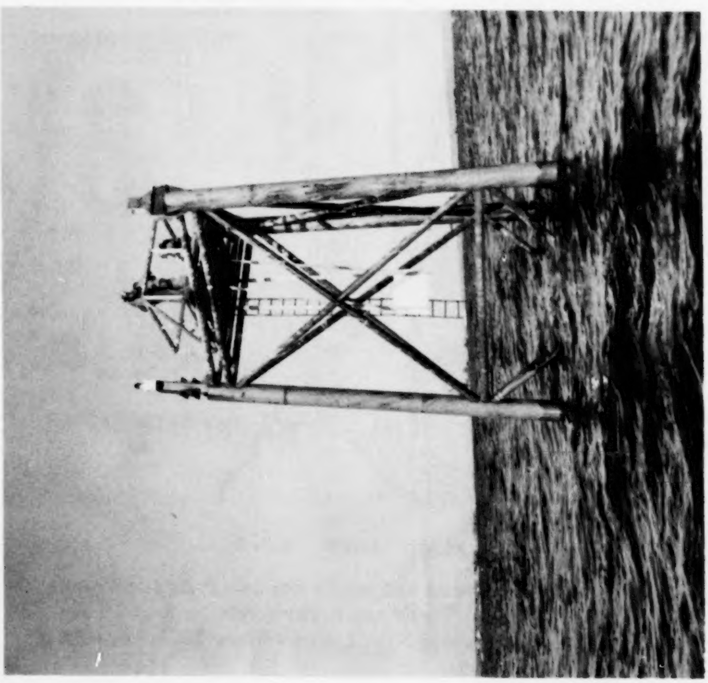

Fig. 2 - Sea tower, made of prefabricated units consisting of 18 inch pipe for the three legs and 4 to 6 inch pipe bracing, was set on bottom by derrick and secured by driving 10 inch steel pipes to firm bearing inside the 18 inch pipes.

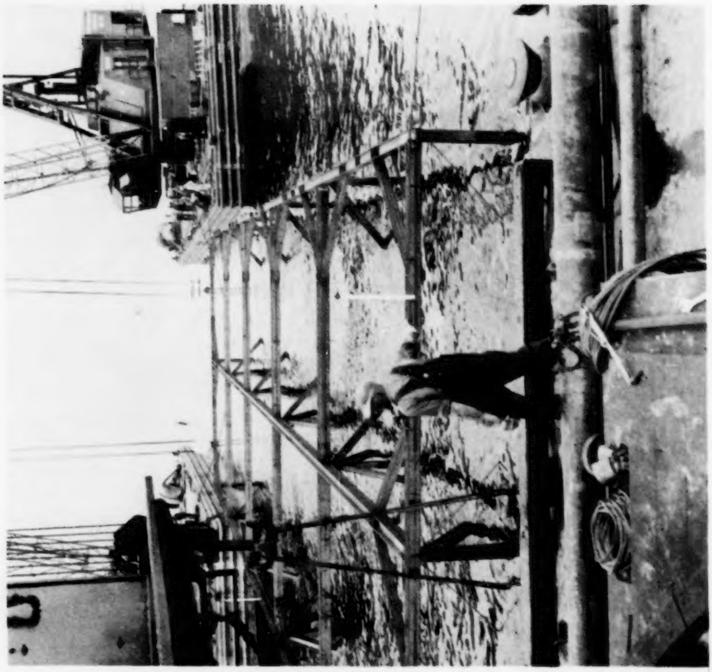

Fig. 3 - Setting cofferdam frame for north anchorage pier. Note white pole markers for lining in the frame to exact position from two sea towers.

Paper 1720 July, 1958 SU 2

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EDUCATION IN SURVEYING AND PHOTOGRAMMETRY IN EUROPE[a]

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(Proc. Paper 1720)

ABSTRACT

This paper presents in some detail the formal education in Surveying and Photogrammetry offered in a number of Western European countries. The various university undergraduate courses in Surveying and Photogrammetry and the graduate studies and degrees are discussed. The offerings of two of the training centres in Photogrammetry are also given.

This paper discusses and gives some details about the education of Surveying and Photogrammetry in five European countries: Switzerland, Germany, Austria, Italy, and Holland.

In all these countries, the civil engineer does not exist as such. The civil engineering field is shared by three categories of engineers: the structural, the surveying, and the cultural engineer. The structural engineer deals with structures, railways and highways, hydraulic works, foundations and soil mechanics, the surveying engineer has surveying as his main field, while the cultural engineer deals with drainage, irrigation, re-allocation, and sanitary engineering as well as surveying. This classification gives the engineer the chance to learn much about his own field, and enables the educational institutions to give the students a thorough education.

In addition to the engineer graduated from the universities or the institutes of technology there is also the technician who graduates from a technical school having mainly to do with the practical requirements of his specialization, without much stress on the theoretical subjects that are not needed in everyday's work. The technician is of great help to the engineer, relieves

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a. Paper presented before the Surveying and Mapping Division at the ASCE Convention in Chicago, Illinois, February 25th, 1958.
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him from many minor works and lets him give more attention to the senior problems. The technician has his limited field and is not allowed to do any job which requires the theoretical knowledge of the engineer. The cooperation between the engineer and the technician in most projects is of great economical advantage to the country. In general, there are about three technicians to every engineer. This figure is not fixed and varies from project to project and from land to land.

In the present paper we shall deal mainly with the education of the engineer.

In Europe, the engineer normally graduates from an institute of technology. There are however a few European universities offering the engineering degree: e.g., the University of Lausanne (Switzerland) and the University of Bonn (Germany). In all these institutions, surveying and photogrammetry courses are offered to the mining engineer, to the structural engineer, to the cultural engineer, as well as to the surveying engineer. In some schools, surveying and also photogrammetry are offered to some other categories of engineers (forestry engineer, geological engineer, architects, etc.). Naturally, the extent of the courses offered vary with the engineer's category, as shown later.

Surveying, as understood in Europe, consists of the following main subjects:

1. Elementary surveying: including the different ways of measuring lengths, angles, heights, etc.; the elements of the theory of errors; topographic mapping; simple triangulations and so on.
2. Advanced surveying: treating precise measurements of angles, lengths, heights; triangulation; deviation of the vertical; etc.
3. Photogrammetry: treating the theory and practice of terrestrial and aerial photogrammetry; working out of projects; training on the stereo-plotting machines; etc.
4. Cartography: treating the theory of modern mapping; drawing and reproduction of various types of maps; etc.
5. Geodesy: treating the determination of the shape and size of the geoid; geodetic lines; geodetic triangulations; etc.
6. Theory of errors and adjustment: as taught to advanced surveying engineers, treats the methods of adjusting correlated and uncorrelated observations in the various engineering problems.
7. Land surveying: treating the necessary theoretical background thereof and giving some practical hints.
8. Astronomy: treating mainly the different methods of determining position and azimuth; introduction to astrophysics; etc.
9. Geophysics: introduction to the physics of the geoid; use of the different methods in determining the underground material and irregularities affecting the field observations of the surveyor; etc.

While the structural and the mining engineers are exposed only to courses in elementary surveying, cartography, photogrammetry and astronomy, the cultural engineer must also attend courses in the theory of errors, land surveying and geophysics and advanced courses in photogrammetry, astronomy, cartography, and surveying. The surveying engineer must further attend even more advanced courses in geophysics, astronomy and cartography.

To go through the required program, the student needs normally 8 semesters. Then he has to spend a last semester in what is called "project" or "Diploma Thesis". Here the students for the surveying and cultural engineering degrees have to work out a project dealing at least with one of the main subjects: advanced surveying, photogrammetry, cartography or geophysics.

After finishing school, each surveying engineer and cultural engineer has to spend a period in practical surveying work before he can apply for a practical exam to earn the title of Land Surveyor and to be allowed to carry out important projects alone; i.e., under his own responsibility. This practical period varies from two to five years depending on the country. The above mentioned land surveyor degree can be earned also by surveying technicians or by engineers of other categories. In such cases, a theoretical exam, virtually covering the whole scope of the theoretical background of the surveying engineer, has to be passed before the practical exam is held. In other words, the surveying or cultural engineering degree replaces the theoretical exam for the land surveyor title. The practical exam is really a tough one. Candidates have to know a lot to be able to pass it.

In general, there are no graduate courses after the diploma. There is no master's degree. The only graduate degree offered is the doctor's degree, which is awarded for successful special scientific research work. It takes normally 2 - 3 years to prepare a doctoral thesis of the required standard.

The different institutions offering the engineering degree are, in general, well organized and very well equipped for their purpose. Just as an example, it can be mentioned that the Surveying Department of the Swiss Federal Institute of Technology consists of the following institutes: The Geodetic Institute, The Institute of Photogrammetry, The Institute of Cartography and the Institute of Geophysics. Each one of these institutes, headed by a full professor has a reasonable separate budget for education, and receives considerable sums of money from the industrial plants and the Swiss Federal Board of Research to carry out important research.

As an example for the equipment, it can be mentioned that the Institute of Photogrammetry in Zurich possesses the following equipment:

1 Wild A7, 1 Wild A6, 1 Wild A5, 1 Wild A2, 1 Wild E1, photo-theodelites, sketchmasters, plus the minor photogrammetric equipment.

In general, the European institutions try to keep always to their high standard in teaching and in research. Years without a single graduation are not a seldom thing there.

Besides the universities and the institutes of technology, there are also special schools for training. In such schools, engineers and technicians are given more training in their special field.

For example, in Milan, Italy, The Photogrammetry Research and Training Centre of the Politechnico of Milan was founded recently with the following aim:

- to develop and promote the study of Photogrammetry in all its branches;
- to turn out engineers and technicians specialized in Photogrammetry, by means of quarterly high courses and special courses of variable duration; such courses are of a formative type and special attention is given to practical training, to seminars and to bibliographical research;
- to act as a consulting body in all the technical and scientific questions relating to any phase of photogrammetry.

In 1951, the Delft Institute of Technology and the Wageningen Institute of Agriculture founded the International Training Centre for Aerial Survey at Delft, Holland for the purpose of providing an institution of higher education in the field of aerial surveying and its associated sciences.

Although the school is located in the Netherlands, its character is entirely international, for students from all over the world, including many from the United States, are enrolled in any one of five courses offered by the school. These courses are photogrammetry, photogeology, photo-interpretation in soils survey, photo-interpretation in forestry, and aerial photography. The course in photogrammetry is, in turn, divided into two parts; a photogrammetric engineering course and a photogrammetric technician's course. The photogrammetric engineering course is the longer of the two, having from one to two years duration and providing a professional man with an education in photogrammetry and its application to map-making. The photogrammetric technician's course takes about one year to complete and gives a man training in various photogrammetric techniques and in the operation of a large number of photogrammetric instruments.

Let us consider the photogrammetric engineering course in more detail. Most of the students enrolled in this course take lectures and laboratory instruction in English. The remainder receive instruction in French or German. Although there are no formal requirements for admission to the school, a candidate for the engineering course should have a B. Sc. degree or its equivalent plus some experience in surveying if he wants to derive the most value from the course. A sound knowledge of analytic geometry, trigonometry and differential calculus is necessary as a great deal of the treatment of the various subjects is mathematical. For those whose knowledge of mathematics is insufficient, a complementary course in mathematics is arranged.

Although the scheduling of lectures and laboratory periods is on a flexible basis at the school, the following breakdown of instruction can be taken as being typical of the program for the photogrammetric engineer's degree.

Lectures

1.	Introduction (History, basic principles optics and stereoscopy)	50 hours
2.	Production of photographs (Cameras, photographic materials, aerial photography, camera orientation in flight)	80 hours
3.	Restitution of photographs (Orientation of photographs, rectification, orientation of pairs, stereoplotting instruments, approximate plotting instruments)	250 hours
4.	Photogrammetric triangulation (Radial triangulation, aerial triangulation and ground control)	180 hours
5.	Production of maps (Cartography, topographic maps, large scale maps, geographical maps, organization and costs of aerial surveys)	130 hours
6.	Theory of errors (Concepts from mathematical statistics, observation series, correlation, laws of propagation of errors, adjustment by the method of least squares)	80 hours
7.	Elementary photo-interpretation (General principles, geomorphology, soils and vegetation forms)	30 hours

Laboratory Work

1.	Parallax bar and point transfer	25 hours
2.	Slotted templet triangulation	75 hours

3. Analytical radial triangulation 75 hours
4. Relative orientation procedures 100 hours
5. Multiplex triangulation 50 hours
6. Aerial triangulation in 1st order instrument 150 hours
7. Precision tests on 1st order instrument 50 hours
8. Plotting maps using various instruments 400 hours
9. Rectification and mosaic preparation 75 hours

This amounts, in total, to 800 hours of lectures and 1,000 hours of laboratory work (or an approximate equivalent of 80 credit hours of lecture and laboratory work). As stated before, this is only a typical case and should not be interpreted as a rigid schedule set by the school. Some students take less time to complete the course; others take more time to do so.

The school has a very large collection of the latest photogrammetric equipment. Students have the opportunity to work on the Nistri Multiple, Williamson Multiplex, Gamble Plotter with Bausch and Lomb Er-55 projectors, Kelsh plotter, Wild Autographs A6, A7 and A8, Santoni Stereocartograph IV, Santoni Stereosimplex II and Stereosimplex III, Poivilliers SOM Stereotopographe B, Zeiss Stereoplanigraphs C5 and C8, Zeiss Stereotope, Santoni Cartographic Micrometer, De Kuipers Plotter, Multiscope, Radial Triangulators, and Wild E2, Zeiss SEG V, and De Koningh Rectifiers. Indeed, about every piece of photogrammetric equipment manufactured today is available at the Centre.

Not only does the International Training Centre for Aerial Survey provide instruction in aerial surveying but it is also very active in photogrammetric research. This gives the student an opportunity to appreciate the work involved in a number of research projects and, in certain instances, to participate in research himself.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1449 is identified as 1449 (HY 6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1957.

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JULY: 1289(SM3), 1290(EM3), 1291(EM3), 1292(EM3), 1293(EM3), 1294(HW3), 1295(HW3), 1296(HW3), 1297 (HW3), 1298(HW3), 1299(SM3), 1300(SM3), 1301(SM3), 1302(ST4), 1303(ST4), 1304(ST4), 1305(SU1), 1306 (SU1), 1307(SU1), 1308(ST4), 1309(SM3), 1310(SU1)c, 1311(EM3)c, 1312(ST4), 1313(ST4), 1314(ST4), 1315 (ST4), 1316(ST4), 1317(ST4), 1318(ST4), 1319(SM3)c, 1320(ST4), 1321(ST4), 1322(EM3), 1323(AT1), 1324 (AT1), 1325(AT1), 1326(AT1), 1327(AT1), 1328(AT1)c, 1329(ST4)c.

AUGUST: 1330(HY4), 1331(HY4), 1332(HY4), 1333(SA4), 1334(SA4), 1335(SA4), 1336(SA4), 1337(SA4), 1338 (SA4), 1339(CO1), 1340(CO1), 1341(CO1), 1342(CO1), 1343(CO1), 1344(PO4), 1345(HY4), 1346(PO4)c, 1347 (BD1), 1348(HY4)c, 1349(SA4)c 1350(PO4), 1351(PO4).

SEPTEMBER: 1352(IR2), 1353(ST5), 1354(ST5), 1355(ST5), 1356(ST5), 1357(ST5), 1358(ST5), 1359(IR2), 1360 (IR2), 1361(ST5), 1362(IR2), 1363(IR2), 1364(IR2), 1365(WW3), 1366(WW3), 1367(WW3), 1368(WW3), 1369 (WW3), 1370(WW3), 1371(HW4), 1372(HW4), 1373(HW4), 1374(HW4), 1375(PL3), 1376(PL3), 1377(IR2)c, 1378 (HW4)c, 1379(IR2), 1380(HW4), 1381(WW3)c, 1382(ST5)c, 1383(PL3)c, 1384(IR2), 1385(HW4), 1386(HW4).

OCTOBER: 1387(CP2), 1388(CP2), 1389(EM4), 1390(EM4), 1391(HY5), 1392(HY5), 1393(HY5), 1394(HY5), 1395 (HY5), 1396(PO5), 1397(PO5), 1398(PO5), 1399(EM4), 1400(SA5), 1401(HY5), 1402(HY5), 1403(HY5), 1404 (HY5), 1405(HY5), 1406(HY5), 1407(SA5), 1408(SA5), 1409(SA5), 1410(SA5), 1411(SA5), 1412(EM4), 1413 (EM4), 1414(PO5), 1415(EM4)c, 1416(PO5)c, 1417(HY5)c, 1418(EM4), 1419(PO5), 1420(PO5), 1421(PO5), 1422(SA5)c, 1423(SA5), 1424(EM4), 1425(CP2).

NOVEMBER: 1426(SM4), 1427(SM4), 1428(SM4), 1429(SM4), 1430(SM4)c, 1431(ST6), 1432(ST6), 1433(ST6), 1434(ST6), 1435(ST6), 1436(ST6), 1437(ST6), 1438(SM4), 1439(SM4), 1440(ST6), 1441(ST6), 1442(ST6)c, 1443(SU2), 1444(SU2), 1445(SU2), 1446(SU2), 1447(SU2), 1448(SU2)c.

DECEMBER: 1449(HY6), 1450(HY6), 1451(HY6), 1452(HY6), 1453(HY6), 1454(HY6), 1455(HY6), 1456(HY6)c, 1457(PO6), 1458(PO6), 1459(PO6), 1460(PO6)c, 1461(SA6), 1462(SA6), 1463(SA6), 1464(SA6), 1465(SA6), 1466(SA6)c, 1467(AT2), 1468(AT2), 1469(AT2), 1470(AT2), 1471(AT2), 1472(AT2), 1473(AT2), 1474(AT2), 1475(AT2), 1476(AT2), 1477(AT2), 1478(AT2), 1479(AT2), 1480(AT2), 1481(AT2), 1482(AT2), 1483(AT2), 1484(AT2), 1485(AT2)c, 1486(BD2), 1487(BD2), 1488(PO6), 1489(PO6), 1490(BD2), 1491(BD2), 1492(HY6), 1493(BD2).

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JANUARY: 1494(EM1), 1495(EM1), 1496(EM1), 1497(IR1), 1498(IR1), 1499(IR1), 1500(IR1), 1501(IR1), 1502 (IR1), 1503(IR1), 1504(IR1), 1505(IR1), 1506(IR1), 1507(IR1), 1508(ST1), 1509(ST1), 1510(ST1), 1511(ST1), 1512(ST1), 1513(WW1), 1514(WW1), 1515(WW1), 1516(WW1), 1517(WW1), 1518(WW1), 1519(ST1), 1520 (EM1)c, 1521(IR1)c, 1522(ST1)c, 1523(WW1)c, 1524(HW1), 1525(HW1), 1526(HW1)c, 1527(HW1).

FEBRUARY: 1528(HY1), 1529(PO1), 1530(HY1), 1531(HY1), 1532(HY1), 1533(SA1), 1534(SA1), 1535(SM1), 1536(SM1), 1537(SM1), 1538(PO1)c, 1539(SA1), 1540(SA1), 1541(SA1), 1542(SA1), 1543(SA1), 1544(SM1), 1545(SM1), 1546(SM1), 1547(SM1), 1548(SM1), 1549(SM1), 1550(SM1), 1551(SM1), 1552(SM1), 1553(PO1), 1554(PO1), 1555(PO1), 1556(PO1), 1557(SA1)c, 1558(HY1)c, 1559(SM1)c.

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APRIL: 1580(EM2), 1581(EM2), 1582(HY2), 1583(HY2), 1584(HY2), 1585(HY2), 1586(HY2), 1587(HY2), 1588 (HY2), 1589(IR2), 1590(IR2), 1591(IR2), 1592(SA2), 1593(SU1), 1594(SU1), 1595(SU1), 1596(EM2), 1597(PO2), 1598(PO2), 1599(PO2), 1600(PO2), 1601(PO2), 1602(PO2), 1603(HY2), 1604(EM2), 1605(SU1)c, 1606(SA2), 1607(SA2), 1608(SA2), 1609(SA2), 1610(SA2), 1611(SA2), 1612(SA2), 1613(SA2), 1614(SA2)c, 1615(IR2)c, 1616 (HY2)c, 1617(SU1), 1618(PO2)c, 1619(EM2)c, 1620(CP1).

MAY: 1621(HW2), 1622(HW2), 1623(HW2), 1624(HW2), 1625(HW2), 1626(HW2), 1627(HW2), 1628(HW2), 1629 (ST3), 1630(ST3), 1631(ST3), 1632(ST3), 1633(ST3), 1634(ST3), 1635(ST3), 1636(ST3), 1637(ST3), 1638(ST3), 1639(WW3), 1640(WW3), 1641(WW3), 1642(WW3), 1643(WW3), 1644(WW3), 1645(SM2), 1646(SM2), 1647 (SM2), 1648(SM2), 1649(SM2), 1650(SM2), 1651(HW2), 1652(HW2)c, 1653(WW3)c, 1654(SM2), 1655(SM2), 1656(ST3)c, 1657(SM2)c.

JUNE: 1658(AT1), 1659(AT1), 1660(HY3), 1661(HY3), 1662(HY3), 1663(HY3), 1664(HY3), 1665(SA3), 1666 (PL2), 1667(PL2), 1668(PL2), 1669(AT1), 1670(PO3), 1671(PO3), 1672(PO3), 1673(PL2), 1674(PL2), 1675 (PO3), 1676(PO3), 1677(SA3), 1678(SA3), 1679(SA3), 1680(SA3), 1681(SA3), 1682(SA3), 1683(PO3), 1684 (HY3), 1685(SA3), 1686(SA3), 1687(PO3), 1688(SA3)c, 1689(PO3)c, 1690(HY3)c, 1691(PL2)c.

JULY: 1692(EM3), 1693(EM3), 1694(ST4), 1695(ST4), 1696(ST4), 1697(SU2), 1698(SU2), 1699(SU2), 1700(SU2), 1701(SA4), 1702(SA4), 1703(SA4), 1704(SA4), 1705(SA4), 1706(EM3), 1707(ST4), 1708(ST4), 1709(ST4), 1710 (ST4), 1711(ST4), 1712(ST4), 1713(SU2), 1714(SA4), 1715(SA4), 1716(SU2), 1717(SA4), 1718(EM3), 1719 (EM3), 1720(SU2), 1721(ST4)c, 1722(ST4), 1723(ST4), 1724(EM3)c.

c. Discussion of several papers, grouped by divisions.

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